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The Influence of Movement Extent, Movement Range and Response Strategy on Distance Reproduction and Recognition

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF Ph.D.

IN

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Fall, 1977

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled THE INFLUENCE OF MOVEMENT EXTENT, MOVEMENT RANGE AND RESPONSE STRATEGY ON DISTANCE REPRODUCTION AND RECOGNITION submitted by CRAIG R. HALL in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Human Performance.

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Supervisor

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Date

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External Examiner

Dedicated to Dianne, my love.

For to be sure it takes time to develop appreciation, understanding and love. Unfortunately most of us are in too much of a hurry trailing something called security to realize the benefits and gratifications nature bestows on those who side with her. We spread ourselves thin and travel the world's pathways at a frantic pace, yet often we fail to catch up with the happiness so avidly pursued. We encumber ourselves with possessions to the point of paralysis. We create ugly scars by tearing what we want from the good earth. We do not see that the earth would gladly give us much more if we only cared enough to be gentle and to take more time.

Andy Russell

ABSTRACT

Twelve experiments were conducted on the influence of movement extent, movement range and response strategy on distance reproduction and recognition. Movements were made with a cursor attached to a linear slide, and vision was eliminated. The effect of movement extent on distance reproduction was for short distances to be more accurately and precisely reproduced than long distances. Differences between short and long distances were also demonstrated in distance recognition. For same judgements short distances were better recognized than long distances, but for difference judgements performance was similar for the two movement distances.

The utilization of a movement range in distance reproductions produced the performance patterns associated with the range effect, the overshooting of short distances and undershooting of long distances. It was further shown that a large number of trials is usually required for range effect tendencies to appear, and these tendencies develop faster for short distances than long distances. These two characteristics and the observation that subjects show differential rates in the development of range effect tendencies prompted the conclusion that the response patterns associated with the range effect are best employed as general performance descriptors for groups of subjects being examined over numerous trials.

Movement range was also found to influence distance recognition. There was a tendency to give *less than* judgements for short distances and *greater than* judgements for long distances when recognition performance was incorrect. A possible relationship between the response

tendencies shown for distance recognition and those associated with the range effect was outlined. The relationship of these tendencies to memory, encoding and comparison processes was also discussed.

An examination of the acceleration, constant velocity and deceleration phases of criterion and reproduction movements indicated that range effect tendencies are a result of the constant velocity phase of reproduction movements being adjusted over trials. For short distances the constant velocity phase was shortened and for long distances this phase was lengthened. The acceleration and deceleration phases of reproduction movements were shown not to be subject to any significant alterations. A model for movement reproduction was proposed based on these findings.

Response strategy, in addition to movement extent and movement range, was also found to modify distance reproduction. Employing bracketing response strategies it was demonstrated that subjects can be under-estimators or over-estimators and that response strategy formation can supercede the central tendencies associated with the range effect. Response strategy as defined in the present research could not be applied to distance recognition; however, the recognition distances in several experiments were manipulated according to bracketing type response strategies. The recognition distances were either physically less than, equal to or greater than the criterion distances. The inclusion of these multiple recognition distances not only improved performance, but reduced the response tendencies reported in recognition judgements where multiple recognition distances were not used.

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Much of the recent literature in psycho-motor behavior is devoted to the short-term recall and recognition of motor items. Recall and recognition refer both to memory processes and test situations, but it is generally the memory processes to which research and theory are directed. Currently one of the most popular and influential accounts of the mechanisms underlying recall and recognition is the generation-discrimination theory (Kintsch, 1970; Brown, 1976). There are two basic processes in this theory, however, only the second one is involved in recognition. The first process entails the generation or retrieval of items from memory storage. Each item then is subjected to a discrimination or recognition test and this test is based on a familiarity judgement. The item judged most familiar will be recalled or selected for recognition in a memory test situation.

The typical experimental paradigm for the examination of short-term retention is the presentation of a criterion item(s), a retention interval which may or may not involve a distractor task, and then recall of the criterion item(s). This paradigm was initially utilized by Brown (1958) and Peterson and Peterson (1959) in experimental psychology, but the first study was not conducted on short-term motor memory until Adams and Dijkstra (1961). Following their lead, numerous researchers investigated retention and interference effects in short-term motor memory (Posner, 1967; Ascoli & Schmidt, 1969; Stelmach, 1969), and more recently, the encoding and retention characteristics of movement attributes (Marteniuk, 1973; Laabs, 1973; Diewart, 1975; Hall & Leavitt, 1977).

A major problem in the examination of the short-term retention of

information is that the only method of assessing the contents of memory is performance on recall and recognition tests. Since memory as measured by performance is also influenced by encoding and retrieval factors, it is difficult to isolate and discuss the various short-term memory processes. This problem is further magnified for short-term motor memory because there are both unconscious and cognitive encoding and retrieval factors particular to motor memory that may alter the reproduction or recognition of the to-be-remembered item. Unconscious components refer to those aspects of a movement that may remain unperceived by the subject but have modifying affects on short-term memory performance and include movement speed, movement extent and movement range.

Woodworth (1899) conducted much of the original research on these components. Accuracy of a movement reproduction was found to decrease as the speed of movement increased. The effect of speed on accuracy of movement reproduction was less pronounced with vision eliminated. Woodworth also showed that when vision was eliminated, faster movement speeds produced movements that were longer than the criterion movement while slower speeds resulted in movements shorter than the criterion movement. At all speeds the preferred hand was more accurate than the non-preferred hand, and long movements were reproduced with greater accuracy than short movements (proportional error). Finally, small movements were regularly exaggerated and large distances were regularly made too small in comparison to the criterion movement. This overshooting tendency for short movements and undershooting tendency for long movements has been termed the range effect (Pepper & Herman, 1970).

Extensive consideration has been given to the range effect in the short-term motor memory literature (Stelmach, 1974; Wilberg & Girouard, 1975). The investigation of central tendencies similar to those associated with the range effect is not a recent development, however, and the work of early investigators such as Delboeuf, Munsterberg and Wundt (Leuba, 1892; Woodworth, 1899) demonstrated judgements of time, weight, force, brightness, area and size of angles have the tendency to gravitate toward a mean magnitude. Hollingworth (1909, 1910) referred to this judgemental shift as the central tendency effect. He proposed that toward the mean magnitude of a range of stimuli each judgement is shifted by virtue of a mental set corresponding to the particular range of concern. The central tendency was considered to be a conceptual process which interferred with the process of comparison and recognition.

Helson (1948) incorporated the central tendency effect into a more general theory of adaptation-level after further and more extensive research on judgements, norms, and frames of reference. The theory of adaptation-level postulates that when subjects lack any standard of comparison they subjectively establish a range of extent and a point within that range which is peculiar to the individual. From the neutral point within the range, stimuli below it are judged as less than and stimuli above it are judged as greater than. Stimuli are judged with respect to the pooled effect of all stimuli, namely, with respect to the adaptation level. The adaptation-level is a region of neutrality or indifference and the neutral point is the mid-value of this region. Stimuli at the extremes of the stimulus range are biased towards the adaptation-level. The central tendency effect is proposed to be a

special case of adaptation-level theory occurring only when the method of single judgement is employed or when the standard is within the stimulus range.

An alternative to adaptation-level theory, the range-frequency model, has been proposed by Parducci (1965). The range-frequency model asserts that category judgements are a compromise between two principles. One principle is concerned with how the stimulus range is divided into categories and the other principle with how frequently the different categories are used. Although the range-frequency model provides a detailed characterization of the relationship between judgement and different features of the stimulus context, the theory of adaptation-level is more simplistic and can more easily account for the central tendency effect.

The range effect in motor short-term memory has been discussed in terms of central tendencies (Pepper & Herman, 1970) and adaptation-levels (Laabs, 1973). Shifts in algebraic error in the direction of the postulated mean distance were attributed by Pepper and Herman (1970) to the central tendency effect. Laabs (1973) included the range effect tendencies in an adaptation-level model based on the theory of Helson (1948). He proposes a movement is made in reference to an average or referent movement in addition to the memory trace of the criterion movement. The referent movement is made up of the combination of movements to be reproduced and is similar in concept to the adaptation-level over the set of movements to be reproduced (Helson, 1964).

Evidence is now accumulating that the range effect for movement information is more complex in nature than existing models indicate.

Most research suggests that the range effect is largely independent of the short-term memory system (Ascoli & Schmidt, 1969; Keele & Ells, 1972; Marteniuk, 1973) since there is little change in the tendencies associated with the range effect over an unfilled delay interval between the criterion and reproduction movements. Some contradictory evidence, however, has been reported by Pepper and Herman (1970) and Laabs (1973). When an interpolated motor act is inserted during a delay interval, strong assimilation tendencies that diminish any range effects are produced in the direction of the interpolated act (Laabs, 1973). These assimilation tendencies are augmented if the reproduction phase closely follows the interpolated motor act (Stelmach & Walsh, 1973). Wilberg and Girouard (1975) have demonstrated that the range effect can be substantially altered by visual information that is associated with the criterion distance. Finally, the manner in which the criterion distances are presented also influences the range effect. Criterion movements actively generated and defined by the subject seem to accentuate the range effect as compared to movements that are experimenter defined (for example, using a tone or a physical stop to indicate the movement end-point) (Wilberg & Tannis, 1974).

Movement reproduction must be subject to and modified by a cognitive component in addition to those factors (movement speed, extent, and range) of which subjects may be unaware. Motor short-term memory investigators, however, have shown little interest in examining or controlling strategies used by subjects in memory experiments. Introspective reports from subjects indicate that much of their time is spent in formulating and testing various coding and retrieval strategies (Stelmach, 1974). These strategies may take a variety of forms

such as verbal labelling and the construction of spatial representations. The adoption of a particular strategy or the changing of strategies could certainly alter performance in a motor memory experiment and an endevour must be made to both control and understand the strategies and rules employed by subjects.

The studies that have examined subject strategies have been primarily concerned with the encoding of movement information (Roy, 1975; N. Gomez-Toussaint & N. Chevalier Girard, 1975) and the maintaining of movement information in short-term memory (Marteniuk, 1973; Duffy, Montague, Laabs & Hillix, 1975). Subject strategies that may influence the reproduction of a movement have not been closely examined. Nevertheless, some of the research done on time estimation may be applicable to movement reproduction. Alderson (1972) has demonstrated that people can be overestimators, underestimators or range-effectors in estimating time. More recently Buckolz (1974) employing an underestimation/overestimation (bracketing) response paradigm has suggested that subjects can form strategies producing response biases which may approximate the central tendencies of the range effect, but not be related to the stimulus range.

Unlike movement reproduction, virtually no interest has been shown to date in the recognition of movement information and factors that may influence recognition performance. Marshall (1972) employed both recognition and reproduction measures to test some propositions of Adams' (1971) closed-loop theory. The theoretical propositions received some support from the experimental results, but more importantly, several significant findings were reported for recognition performance. Increases in criterion movement length produced increases

in the mean proportion of correct responses. Multiple (six) reinforcements resulted in superior performance to one reinforcement and performance decreased as discriminability of the criterion movement from alternative criterion movements decreased. Finally, recognition tended to decrease as the retention interval between the criterion and recognition movements increased.

Kantowitz (1974) evaluated motor short-term memory in a same-different recognition task arguing that recognition measures offer certain methodological advantages over reproduction measures of retention. Recognition does not require the accurate generation of a movement terminating at a specific location, a task which appears to become more difficult as movement distance increases (Fitts, 1954). Furthermore, the criterion and test trials for recognition are identical but this is generally not the case for reproduction. The criterion movement in a reproduction task is usually experimenter-defined and favours movement at a constant velocity to the end-point stop. The reproduction movement is subject defined and involves a strategy of deceleration as the movement end-point is approached. This performance of two different types of movement strategies in a reproduction task may make it unclear what is being tested for retention (Bahrick, Fitts & Schneider, 1955).

Kantowitz (1974) found that there was no decrease in recognition performance for movement information over a retention interval involving interpolated activity. This finding is in opposition to the results reported by Marshall (1972) but may be contributable to the different experimental paradigms used in the two studies. Marshall employed a two-interval forced-choice recognition task as opposed to

the same-different judgements Kantowitz utilized. Kantowitz also demonstrated that performance was best for *different-over* trials and worst for *different-under* trials, with the *same* performance being intermediate. He referred to this tendency as an undershooting set, but unlike Pepper and Herman (1970), used this term as a descriptive rather than explanatory concept.

The purpose of the following series of experiments was to investigate some of the characteristics of movement distance reproduction and recognition in order to gain an understanding of how movement extent, movement range and subject strategy operate in modifying the reproduction and recognition of a distance. A secondary purpose of these experiments was to examine some encoding and retrieval variables that are important in motor short-term memory tasks and may interact with movement extent, movement range and subject strategy to influence movement reproduction and recognition. In Experiment 1 the retention of movement distance over time was investigated to determine if the maintenance of distance information in short-term motor memory was a significant factor in the present research. Previous research has produced some conflicting findings on this issue. Marteniuk and Roy (1972), Marteniuk (1973) and Hall and Leavitt (1977) all reported that distance reproduction performance did not deteriorate over time. Pepper and Herman (1970) and Laabs (1973) found the spontaneous decay of distance over an unfilled retention interval. This issue had to be investigated before additional experiments could be undertaken. The second purpose of Experiment 1 was to examine the applicability of the bracketing response paradigm (Buckolz, 1974) in distance reproduction.

The development and locus of the range effect was the concern of Experiments 2-4 and Experiment 6. Several researchers (Pepper & Herman, 1970; Laabs, 1973) have reported the central tendencies associated with the range effect in short-term motor memory experiments, but have not considered the development of these tendencies over trials. Similarly, Wilberg and Girouard (1975) have proposed a central, encoding-related locus for the range effect but additional research was required to substantiate this proposal.

The implementation and affect of response strategies on distance reproduction was considered in Experiments 5, 7 and 8. Buckolz (1974) utilized bracketing response strategies in experiments on time estimation and it was hypothesized that similar strategies would be useful for the investigation of distance reproduction. The influence of encoding instructions and type of criterion movement end-point on distance reproduction were also analyzed in Experiments 5 and 8, respectively. With the exception of a study by Wilberg and Tannis (1974) on end-point control, research on these variables has not been reported in the short-term motor memory literature.

The criterion and reproduction distances used in Experiments 1-8 were subject produced, self-paced movements that were either subject or experimenter defined. Self-paced movements were employed to reduce any effects of changing speeds on movement reproduction (Woodworth, 1899). The movements were subject produced since there is evidence indicating performance is altered on a motor short-term memory task when criterion movements are passively presented rather than actively generated by the subject. Marteniuk (1973) and Jones (1974) both have shown that active movement not only results in better immediate repro-

duction but that it is also retained better over time than passively induced movement.

Distance recognition performance and any response tendencies associated with distance recognition judgements were considered in the final four experiments of the present research. The utilization of a recognition paradigm to examine the short-term retention of movement information has been limited to a few studies (Marshall, 1972; Kantowitz, 1974) and further research in this area was regarded as necessary. These four recognition experiments in conjunction with the reproduction experiments were designed to provide a basis for understanding how factors such as movement extent, movement range and response strategy influence movement recognition and reproduction. Consideration of these factors should clarify some of the difficulties currently existing in the examination of to-be-remembered items in short-term motor memory.

Experiment 1

Response Strategy, Retention Interval and Distance Reproduction

Encoding, the transformation of information within the human processing system from one form or state to another, has recently become a popular concern in the verbal and visual memory literature (Melton & Martin, 1972; Melton, 1973; Ellis, 1973) and, to a lesser degree, has been examined in short-term motor memory (Stelmach, 1974; Marteniuk, 1975). Conceivably the memory for different motor tasks may require encoding different types of information each with its own unique retention characteristics. The majority of investigations have examined distance and location information employing simple linear and angular movement reproductions.

While the research conducted on location information has produced relatively consistent results (Marteniuk, 1973; Laabs, 1973), the findings for distance information have been somewhat ambiguous. Laabs (1973), varying the retention interval in a reproduction accuracy task, reported distance information spontaneously decays over time. Laabs argued, therefore, that distance information is kinesthetically encoded (not subject to central memory processes such as rehearsal). In contrast, Marteniuk (1973) found that reproduction accuracy for distance information did not decrease spontaneously, but was influenced by interpolated activity during the retention interval. Based on these results Marteniuk suggested that distance information is centrally encoded and subject to such processes as interference and rehearsal. Recently, Jones (1974) has suggested that the conflicting findings for the retention of distance information are the consequence

of the methodology employed in the experiment. When the criterion movement is defined by the experimenter (Laabs, 1973) distance information is kinesthetically encoded. If the criterion movement is defined by the subject (Marteniuk, 1973), distance information is encoded centrally.

Diewart (1975) in re-examining the encoding and retention characteristics of movement distance suggests that Marteniuk (1973) and Laabs (1973) are both partially correct in their analysis of distance. He reports that distance is centrally coded in that it can be retained over an unfilled retention interval. Nevertheless, distance appears to be coded in a non-visual or kinesthetic store. This conclusion was based on the different effects of kinesthetic and visual interference on the retention of distance. Kinesthetic interference had a detrimental influence on distance reproduction while visual interference tended to prevent rehearsal but did not have a structural interference effect.

Although the exact nature of the encoding of distance information is uncertain, several basic characteristics of distance reproduction have been determined. When an interpolated motor act is inserted during a delay interval, strong assimilation tendencies are produced in the direction of the interpolated task (Pepper and Herman, 1970; Laabs, 1973). These tendencies are augmented if the reproduction phase closely follows the interpolated motor act. Moreover, Pepper and Herman (1970), Herman and Bailey (1970), and Craft and Hinrichs (1971) have all demonstrated reproduction errors proportional to the magnitude of the interpolated movement. Another consideration involves the memory trace strength of the criterion distance. Stelmach and

Kelso (1975) contend memory trace strength is a determiner of error shifts in reproduction accuracy at recall.

One of the most important characteristics in the reproduction of movement distance is the range effect; the tendency to overshoot small distances and undershoot large distances. Buckolz (1974) employing a bracketing response paradigm for time estimation has demonstrated that subjects can be over-estimators or under-estimators and tendencies in time estimation data that correspond with range effect tendencies may be due to the response strategies adopted by the subjects. The experimental paradigm utilized by Buckolz (1974) was postulated by the present authors to be a viable alternative to the simple reproduction accuracy task generally employed in distance reproduction research. It was further hypothesized that the incorporation of this paradigm in a motor memory experiment might provide some insight into the encoding, retention characteristics, and range effect for distance information. In the present experiment the applicability of the bracketing paradigm in a distance reproduction task was examined. A varied retention interval was used to ascertain whether distance information could be encoded and retained over time as Marteniuk (1973) and Diewart (1975) contend.

Method

Subjects

The subjects were six students from the University of Alberta who wrote with their right hand.

Design

Subjects were tested on the reproduction of a short (5 cm) and long (25 cm) criterion distance according to either a just less than (1 jnd) or just greater than (1 jnd) response strategy. The four possible response requirements were reproduction of a distance (1) just less than the criterion short distance, (2) just greater than the criterion short distance, (3) just less than the criterion long distance, and (4) just greater than the criterion long distance. The three retention intervals were immediate reproduction, reproduction after 10 seconds of rest, and reproduction after 20 seconds of rest. Therefore, the experimental design was a 4 x 3 factorial with repeated measures on both factors. Each treatment condition was replicated ten times by each subject. The movement lengths were randomized within the retention interval conditions.

Apparatus and Task

The apparatus consisted of a 4.0 by 125.0 cm brass bar, used as a track, mounted on a wooden frame. The track was calibrated in mm. A metal cursor with a small handle was employed in making the reproductions. A second cursor with a screw-lock was employed as a physical stop to designate the end-points of the criterion distances. The length of the retention intervals was timed using a Hunter interval

timer (model 111-C). The auditory signal for recall was produced by system consisting of a Bogen Challenger amplifier (CHB20A), an Eico audio generator (model 377), and a three inch speaker. The subjects were blindfolded and sat comfortably in front of the apparatus moving the cursor horizontally from the left to right. The range used on the track was 60.0 cm.

Procedure

The subject was presented a criterion distance by having him actively move the cursor from one of nine random starting positions to a stop. The position was held by the subject for approximately two seconds, and then he released his grasp of the cursor handle. During the specified retention the subject rested his hand on a bar in front of the apparatus. The cursor was repositioned to a different starting position during the retention interval thereby making location information unreliable for the reproductions. In the immediate reproduction condition there was no designated retention interval, but a two second interval (a constant for each retention interval condition) while the cursor was repositioned for the reproduction. When a tone marked the end of the retention interval, the subject regrasped the cursor handle and produced the appropriate response. After the reproduction the distance was recorded to the nearest mm.

Data Analysis

Signed constant error (CE) or mean signed algebraic error; variable error (VE), the standard deviation of the CE; absolute error (AE) or unsigned error; and average variation (AV), the standard deviation of the AE, were each submitted to a separate analysis of variance.

Results

For all error scores response strategy was significant, $F(3,180) = 28.90$, $p<.01$ for CE; $F(3,180) = 22.20$, $p<.01$ for VE; $F(3,180) = 20.15$, $p<.01$ for AE; and $F(3,180) = 21.00$, $p<.01$ for AV (Table 1). The Duncan test revealed that in each case there was a significant difference ($p<.05$) between the response strategy conditions for short criterion distances and long criterion distances.

For retention interval, CE and AV failed to reach significance ($p>.05$). Retention interval for the other error scores was significant, $F(2,180) = 31.02$, $p<.01$ for VE; and $F(2,180) = 12.01$, $p<.05$ for AE. Analysis with the Duncan test indicated improved performance for the longer retention intervals compared to immediate reproduction. The only interaction between response strategy and retention interval was for CE, $F(6,360) = 11.21$, $p<.05$.

TABLE 1

CE, VE, AE and AV for the Response Strategies

Response Strategies	CE	VE	AE	AV
Short Distance				
Less Than	-0.52	1.34	1.30	0.85
Greater Than	2.34	1.64	2.50	1.46
Long Distance				
Less Than	-3.42	3.68	4.29	2.80
Greater Than	0.59	3.74	3.09	2.54

Values in cm

Discussion

It was demonstrated that there was no decrease in distance reproduction performance in terms of both accuracy and precision over an unfilled delay interval. These results suggest distance information is encoded at a level which allows it to be maintained over short time periods and that it is probably subject to rehearsal processes (Martenuk, 1973; Hall & Leavitt, 1977). From the presented results it is not possible to determine if distance information was coded in a non-visual or kinesthetic store as proposed by Diewart (1975).

The bracketing paradigm was found to be applicable in distance reproduction tasks since subjects were able to make the appropriate reproduction, for both short and long distances, corresponding to the required response strategy. Response strategy, as defined in the experiment, was shown to be largely independent of the short-term motor memory system since there was no change in response strategy over an unfilled retention interval. No inferences concerning the range effect could be drawn from the experimental results since the necessary control condition, accurate reproduction of the criterion distance, was not incorporated as a response strategy.

Experiment 2

Range Effects for Distance Reproduction

The range effect has been commonly reported in motor short-term memory studies employing a movement reproduction accuracy task. A survey of these studies has produced a more precise understanding of this phenomenon. Most evidence suggests that the range effect is largely independent of the short-term memory system. There is little change in the range effect, as measured by signed CE, over an unfilled delay interval (Ascoli & Schmidt, 1969; Keele & Ells, 1972; Marteniuk, 1973). The range effect is influenced by interpolated motor acts (Pepper & Herman, 1970), the method of presentation of the criterion movement items (Wilberg & Tannis, 1974), and the memory trace strength of the criterion movement items (Stelmach & Kelso, 1975). The range effect in short-term motor memory has been discussed in terms of assimilation effects (Pepper and Herman, 1970) and adaptation-levels (Laabs, 1973). The model by Laabs (1973) proposes a movement is made in reference to an average or referent movement in addition to the memory trace of the criterion movement. The referent movement is made up of the combination of movements to be reproduced and is similar in concept to the adaptation-level over the set of movements to be reproduced (Helson, 1964). It now appears that the range effect for movement information is more complex in nature than existing models indicate. Wilberg and Girouard (1976) have demonstrated that the range effect can be substantially altered by visual information that is associated with the criterion distance and visual information effects short and long movements differently. The range effect for distance reproduction is investigated over trials in this experiment to gain a further understanding of how the central tendencies develop for short and long distances.

Method

Subjects

The subjects were six students from the University of Alberta who wrote with their right hand.

Design

A single treatment condition, movement distance, with two levels, short (5.0 cm) and long (25.0 cm), was employed. Subjects received 15 trials for each movement distance, the movement distances being randomly distributed over the 30 trials.

Apparatus and Task

A meter bar (not calibrated) mounted on a dexion frame served as the track on which the distances were produced by the subjects. A plastic cursor with a metal handle was utilized for making the various distances. The cursor was attached to a 10-turn potentiometer whose output, after being passed through a voltage/amplifier box was fed into a digital multimeter (Fluke 8000 A). Therefore, when the cursor was moved, the distance traversed was recorded by a change in the digital output of the multimeter (mv).

The blindfolded subject sat comfortably in front of the apparatus and moved the cursor from his left to right with the right hand. The range used on the meter bar was 65.0 cm, all distances being made within that range. A plastic distance marker and an adjustable stop were mounted on the dexion frame, parallel to the track in order that the exact criterion distance could be presented to the subject.

Procedure

On each trial the subject had to reproduce a criterion distance, location information being made irrelevant with the use of 12 possible starting locations. The subject was presented with a criterion distance by having him move the cursor until it contacted a physical stop. The subject held this position for approximately two seconds and then he released his grasp of the handle. The cursor was then repositioned to a different starting position and immediately a command was given to accurately reproduce the criterion distance. After the subject regrasped the cursor handle and made his reproduction, the distance was recorded to the nearest mm. The same error scores as those in the previous experiment were computed.

Results

CE for movement distance was not significant ($p>.05$) with the short distance condition being 12.95 mm and the long distance condition being 6.30 mm. This result was not expected since long distances are generally associated with undershooting tendencies. An examination of CE over trials indicated an ordered effect for long distances (Figure 1) with an increasingly negative trend in CE. In addition, it was found that four of the six subjects were demonstrating undershooting for long lengths after 30 trials, as expected.

AE for movement distance was significant, $F(1,24) = 8.59$, $p<.01$. For the short distance AE was 16.13 mm while for the long distance it was 29.25 mm. This difference between the short and long distances is altered if absolute error is examined as a proportion of the criterion distance. Absolute error is actually a smaller proportion of the long criterion distance (.12) than the short criterion distance (.32). The short distance (11.17 mm) was also significantly different from the long distance (33.26 mm), $F(1,84) = 22.25$, $p<.01$, for VE. Proportional VE, however, was less for the long distance (.13) than the short distance (.22). Finally, the results for AV followed the same pattern, $F(1,24) = 16.33$, $p<.01$, the short distance (9.70 mm) being associated with the smaller error (long distance, 26.26 mm). Proportional AV was again less for the long distance (.10) than the short distance (.19).

Subjects were given a questionaire following the experiment and reported difficulty in determining the movement range (two criterion distances). Estimates of the number of criterion distances varied from 2-5 with subjects usually reporting an intermediate distance.

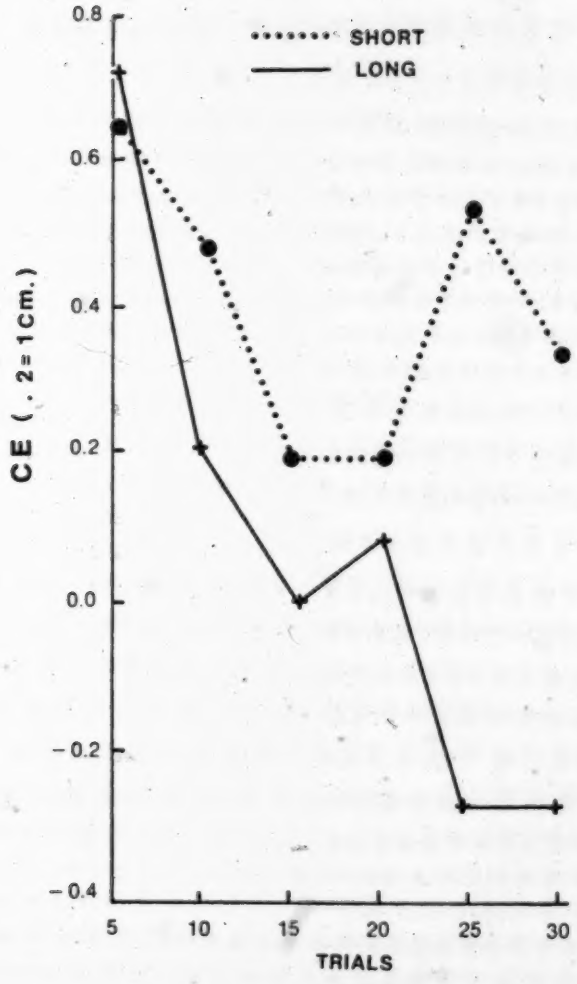

Figure 1. CE over trials for the short and long distances.

Discussion

A large number of trials, in the present study over thirty, is usually required for subjects to determine the experimental movement range and produce the characteristic central tendencies. The consistent overshooting of short distances may be shown prior to the consistent undershooting of long distances. Two subjects in this study failed to produce the central tendency for the long distances after thirty trials. This finding and the fact that subjects show differential rates in their determination of the movement range lend support to the contention of Buckolz (1974) that performance patterns described by the range effect are just general descriptors, and may not be useful in attempting to predict individual performance.

Corresponding with previous research (Pepper & Herman, 1970; Laabs, 1973), short distances were more accurately reproduced than long distances for AE and VE. This seems to indicate that the information from long distances is not as available for the execution of accurate and precise reproductions as is the information from short distances. However, while the numerical size of the errors (VE, AE and AV) was greater for the long distance, the perceptual size of the errors may have been no larger. The proportional size of the errors was smaller for the long distance than the short distance. These results suggest the encoding of distance information may be on some sort of relative magnitude basis (Henry, 1976) and information from short and long distances is equally available for distance reproduction (Diewart, 1975).

Experiment 3

Distance Estimation

A characteristic usually associated with movement reproduction is the range effect, the tendency to overshoot short movements and undershoot long movements. Numerous studies (Pepper & Herman, 1970, Laabs, 1973; Buckolz, 1974) have reported the central tendencies of the range effect, but it is only recently that this phenomenon has been given detailed consideration. The development of the range effect was examined over trials in Experiment 2. The consistent overshooting of short distances was demonstrated prior to the consistent undershooting of long distances, and a large number of trials (30) was required before subjects determined the experiment movement range and produced these central tendencies. Moreover, since subjects showed very different rates in the development of the range effect, the author concluded that performance patterns described by the range effect are general descriptors, and may not be useful in attempting to predict individual performance.

Several studies have produced evidence suggesting the range effect may be related to encoding processes. Wilberg and Tannis (1974) demonstrated that the type of criterion movement end-point influences the appearance of the range effect. The overshooting of short movements and undershooting of long movements characterized the reproduction of criterion movements terminated by a physical stop and sound off but not movements terminated by the subject or with sound on. Wilberg and Girouard (1976) showed that the range effect for movement information can be substantially altered by visual information provided at the same time as the criterion movements, and this visual information

effects short and long movements differently. The authors concluded that an important source of the range effect may be central, encoding-related processes.

The purpose of the present study was to further consider the development and locus of the range effect for movement utilizing an estimation task rather than the conventional technique of movement reproduction. Subjects were required to estimate short and long distances from memory. It was hypothesized that if the range effect is generated by central, encoding-related processes the performance patterns associated with the range effect would not be produced in the present experiment since the processes involved in the acquisition and comparison of movement information would make a minor contribution to performance in a distance estimation task.

Method

Subjects

The subjects were eight students from the University of Alberta who wrote with their right hand.

Design

Two estimated movement distances, short and long, were utilized in the study. Each movement distance was replicated 15 times by each subject, the movement distances being randomly distributed over the 30 trials. Subjects also received 6 test trials for each of their criterion short and criterion long distances.

Apparatus and Task

A meter bar (uncalibrated) mounted on a dexion frame served as the track on which distances were produced by the subject. A metal cursor with a handle was utilized for making the various distances. The cursor was attached to a 10-turn potentiometer whose output, after being passed through a voltage divider/amplifier box, was connected to both a PDP-11 computer and a Fluke 8000A digital multimeter. Therefore, when the cursor was moved, the distance traversed was recorded by both the computer and multimeter as a change in mv. A Bodgen Challenger CHB 20A amplifier, an Eico audio generator, and a speaker were used to produce tones signalling the start of the testing and the completion of trials. A light indicated the start of a trial and both the tones and light were computer programed.

The subject sat comfortably in front of the apparatus and moved

the cursor from his left to right with the right hand. The subjects' vision of the slide and cursor was blocked by a raised platform that covered the apparatus. Along the front and side edges of the platform was a short fringe cloth. Mounted parallel to the metal track was a wooden track calibrated in mm. An extended metal cursor was moved along this wooden track by the experimenter and the cursor acted as a physical stop for the presentation of the movement range.

Procedure

A movement range of 0.0 - 30.0 cm was initially presented to each subject by having him move the cursor between two physical stops. The subject was next requested to produce a short distance and a long distance within that range. The subject was told these two distances were to be his criterion distances for the remainder of the experiment. The subject was given practice producing his two criterion distances according to the following format. The subject produced his criterion short distance, his criterion long distance, and then moved the cursor to a physical stop set at the midpoint (15.0 cm) of the original movement range. Distances were produced from six different starting points to make location information irrelevant.

Following the practice session the subject was examined over 12 trials on his criterion distances, producing first the short distance and then the long cirterion distance. The subject was then tested over 30 trials on estimating these short and long distances with their order being random. Each trial consisted of the subject grasping the cursor and producing the distance requested by the experimenter

for that trial. Again six different starting points were utilized to make location information irrelevant.

Data Analysis

Algebraic error (CE), variable error (VE), and absolute error (AE) were calculated and velocity was measured for both criterion and reproduction movements.

Results

Movement distance for CE was not significant ($p>.05$) being 0.7 cm for the short distance and 1.7 cm for the long distance. As indicated in Figure 2, no significant changes were demonstrated in CE over trials for either the estimated short or long distance. Variable error for estimated movement distance was significant, $F(1,98) = 8.81$, $p<.01$. For the short distance the variable error was 1.21 cm while for the long distance it was 3.10 cm. AE for estimated movement distance also failed to reach significance ($p>.05$) with the error for the short distance being 1.1 cm and for the long distance being 2.7 cm. The estimated short and long distances were significantly different for average velocity, $F(1,98) = 11.07$, $p<.05$. The average velocity for the short distance was 4.5 cm/sec while the average velocity for the long distance was 9.9 cm/sec.

There were no significant differences between the respective criterion and estimation distances ($p>.05$). The average criterion short distance was 5.3 cm and the average estimated short distance was 5.9 cm. The average velocity for the criterion short distance

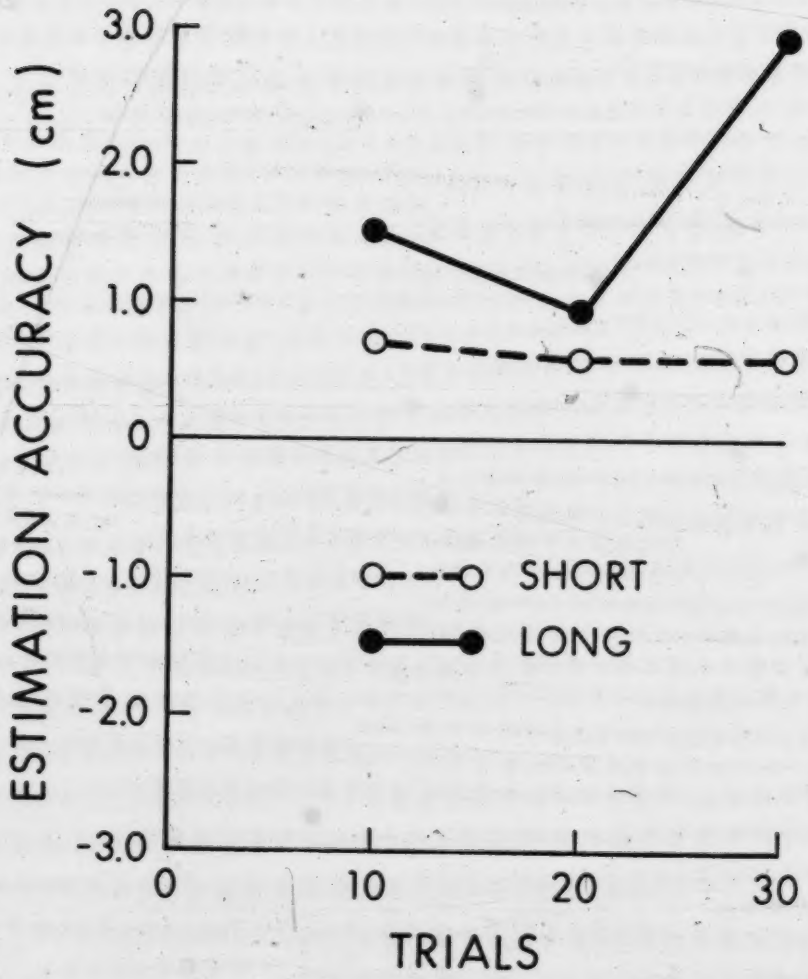

Figure 2. Estimation accuracy (CE) for the short and long distances over trials.

was 4.1 cm/sec while the average velocity for the estimated short distance was 4.5 cm/sec. The average production times for the criterion and estimated short distances were identical, 1.3 sec. The average criterion long distance was 27.1 cm with a production time of 2.6 sec. The average estimated long distance was 28.7 cm and was made in a time of 2.9 sec. The average velocity for the long criterion distance was 10.4 cm/sec while the average velocity for the estimated long distance was 9.9 cm/sec. Subjects were very consistent at producing the criterion distances when examined over the 12 test trials. The standard deviations for the short criterion distance ranged from 0.4 - 1.2 cm while the standard deviations for the long criterion distance ranged from 0.6 - 3.5 cm.

Discussion

The reproduction of a range of distances is generally characterized by the range effect, and evidence in several studies (Wilberg & Tannis, 1974; Wilberg & Girouard, 1976) suggests an encoding-related locus for this phenomenon. Short and long distances were estimated from memory in the present experiment and it was shown that in this situation the central tendencies associated with the range effect failed to develop over trials. These results support a perceptual/cognitive locus for the range effect. Response processes do not appear to be a source for the development of central tendencies in reproduction performance since the response requirements in the present experiment and those in previous distance reproduction experiments (Experiment 2) were highly similar. Furthermore, these tendencies also are largely inde-

pendent of motor memory since there is little change in algebraic error over an unfilled retention interval (Keele & Ells, 1972; Marteniuk, 1973; Wilberg & Girouard, 1976).

The central tendency effect not only develops when a range of movements are reproduced, but is demonstrated in such areas of experimental psychology as magnitude estimation, reaction time, stimulus generalization, threshold measurement and probability assessment (Poulton, 1974). Helson's (1947, 1964) adaptation level theory has been extensively used to explain the central tendency effect. The basic concept in this theory is that the perceptual judgement of a stimulus depends upon its relationship to the adaptation level, and in the case of single judgements, its relationship to the standard. A subject produces a movement in relationship to the criterion movement (standard) on each trial of a movement reproduction experiment, and according to adaptation-level theory movements at extremes of the stimulus range should be biased towards the adaptation-level, therefore producing the performance patterns associated with the range effect.

In the present experiment there was no criterion distance presented for reproduction. A stimulus range of perceived distances for which an adaptation level could be established was also not available. It would appear, therefore, that in the present experiment an important processing stage not required was the comparison of the produced distance to a standard and adaptation level. The subjects simply made distances from memory. When the range effect is demonstrated in an experiment, the stage for the comparison between the reproduction and criterion movements may be subject to change over trials, the result being the overshooting of short distances and the undershooting of long

distances. Changes in this comparison stage could be altered by the manner in which the criterion and reproductions movements are encoded, as suggested by the research of Wilberg and Girouard (1976).

Previous research (Pepper & Herman, 1970; Laabs, 1973) has shown short distances are more accurately reproduced than long distances and Marteniuk (1973) suggests this difference may be linked to differential central processing capacities for movement length information. When distances are produced from memory as in the present experiment long distances and short distances are made with similar accuracy. Furthermore, when proportional errors are examined for movement reproduction, differences between short and long movements disappear (Diewart, 1975). These results indicate that various movement lengths are encoded and processed in the same manner and are equally available in memory for the production of distances. Differences reported between the reproduction of short and long distances may be due to the encoding of distance information on some sort of relative magnitude basis, as suggested in the previous experiment.

Marteniuk, Shields and Campbell (1972) found that subjects used the same relative velocity of movement for both criterion and reproduction movements. Since velocity of movement also correlated poorly with the accuracy of movement reproduction, they concluded that velocity has little influence on movement reproduction. Average velocity of the criterion and estimation distances for both short and long movements were not significantly different in the present study. Consequently, velocity may also play a minor role in the estimation of distances from memory, similar to that demonstrated for movement reproduction.

Experiment 4

Reproduction of Visually Presented Distances

Several researchers (Wilberg & Tannis, 1974; Wilberg & Girouard, 1976) and the findings of Experiment 3 suggest that the range effect is related to encoding and comparison processes and is not affected by memory and response processes. Therefore, provided accurate encoding of the criterion distance is possible, the central tendencies associated with the range effect should appear in distance reproduction experiments regardless of the method of presentation of the criterion distance. The purpose of the present experiment was to examine any range effect tendencies when the criterion distances to be reproduced were presented visually rather than kinesthetically.

Previous motor memory studies incorporating visual and kinesthetic information have generally entailed the presentation of the criterion movement in both modalities (visually guided movement) but reproduction in only the kinesthetic modality (blind positioning movement). Posner (1967) found no significant difference in accuracy of immediate reproduction between kinesthetic and visual plus kinesthetic conditions. The presence of visual information, however, can disrupt the acquisition of kinesthetic information if the two types of input are conflicting (Klein & Posner, 1974). Performance also seems to be biased to visual information under such conditions. Annett (1970) reported the marked overshooting of movements when visual information was amplified over kinesthetic information (approximately a ratio of 2:1). Similar results were demonstrated by Wilberg and Girouard (1975) in their investigation of range effects. Using kinesthetic-visual disparity it was shown that when visual information

was short at the time of presentation, kinesthetic information was undershot at recall. When visual information was long, kinesthetic information was overshot at recall. Therefore, it is possible to reverse the tendencies associated with the range effect by an assimilation process with visual information. The range effect, nevertheless, seems to depend on the reproduction modality since it was also found that the range effect was much more pronounced in the kinesthetic than in the visual plus kinesthetic modality.

Method

Subjects

The subjects were eight students from the University of Alberta who wrote with their right hand.

Design

The experiment consisted of a single treatment condition, movement distance, with two levels: short (5.0 cm) and long (25.0 cm). Each movement distance was replicated 15 times by each subject, the two movement distances being randomly order.

Apparatus and Task

A meter bar (uncalibrated) mounted on a dexion frame served as the track on which distances were produced by the subject. A metal cursor with a handle was utilized for making the various distances. The cursor was attached to a 10-turn potentiometer whose output, after being passed through a voltage divider/amplifier box, was connected to both a PDP-11 computer and a Fluke 8000A digital multimeter. Therefore, when the cursor was moved, the distance traversed was recorded by both the computer and multimeter as a change in mv. A Bodgen Challenger CHB 20A amplifier, an Eico audio generator, and a speaker were used to produce tones signalling the start of testing and the completion of trials. A light indicated the start of a trial and both the tones and light were computer controlled. Criterion distances were presented on a Statham 700-170 oscilloscope by the movement of a dot of light (1.6 mm diameter) from the left to the right of the viewing screen. The

distances presented on the oscilloscope were computer programed.

The subject sat comfortably in front of the apparatus and moved the cursor from his left to right with the right hand. The subject's vision of the slide and cursor was blocked by a raised platform which covered the apparatus. Along the front and side edges of the platform was a short fringe cloth.

Procedure

A trial was initiated by the onset of a light. At this signal the subject grasped the cursor and focused his attention on the dot of light on the oscilloscope screen. Following a 5 sec delay interval that started with the onset of the signal light, the dot on the screen moved from the left to right the criterion distance (5.0 cm or 25.0 cm). Immediately following the presentation of the criterion distance the subject attempted to accurately reproduce this distance on the slide. A tone signalling the end of the trial was produced when the subject completed his reproduction. Six different starting points were used on the slide. The distance reproduced by the subject was recorded in mm.

Data Analysis

Algebraic error (CE), variable error (VE), absolute error (AE) and average variation (AV) were calculated over trials. Subjects were also asked several questions about the experiment.

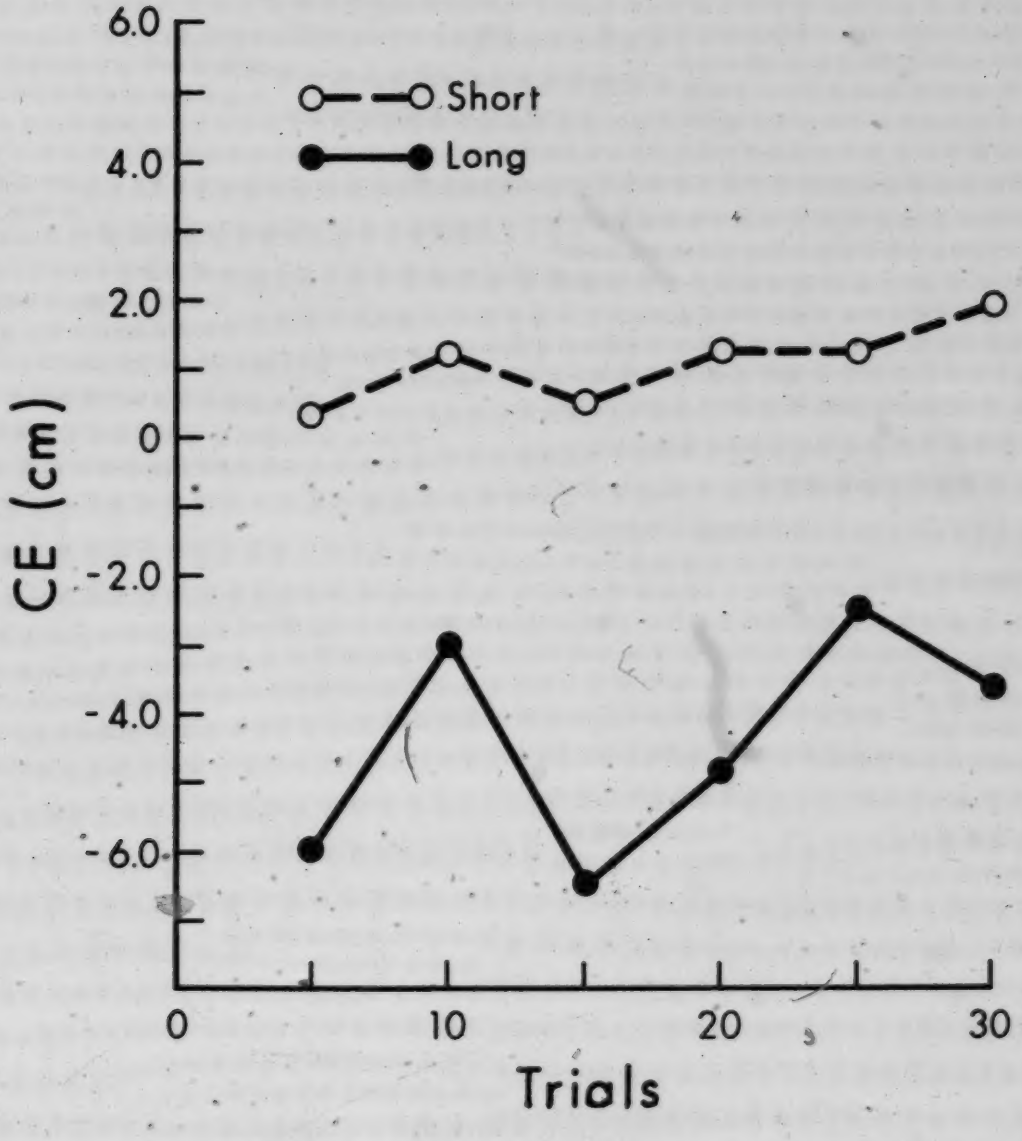

Figure 3. CE for the short and long distances over trials.

Results

Movement distance for CE was significant, $F(1,98) = 15.14$, $p<.01$. The short distance (5.0 cm) was 1.10 cm and the long distance (25.0 cm) was -4.44 cm. CE for the short and long distances over trials is shown in Figure 3. Movement distance was also significant for VE, $F(1,98) = 17.76$, $p<.01$, the short distance being 0.94 cm and the long distance being 2.18 cm. Similar results were found in the other two error measures. AE was significant, $F(1,98) = 6.97$, $p<.01$, the short and long distances being 1.54 cm and 5.78 cm, respectively. Movement distance for AV was significant, $F(1,98) = 13.23$, $p<.01$. The short distance was 0.80 cm and the long distance was 1.89 cm.

In answering a questionaire following the experiment subjects reported no difficulty in rapidly assessing the movement range (two distances) but indicated a lack of confidence in their performance.

Discussion

The central tendencies associated with the range effect are generally reported in experiments involving the reproduction of a range of movement distances (Pepper & Herman, 1970; Laabs, 1973). The work of previous researchers (Keele & Ells, 1972; Wilberg & Girouard, 1975) and the findings reported in Experiment 3 indicate that the range effect is independent of memory processes. Results provided by Trumbo, Milone and Noble (1972) and Experiment 3 further suggest that response mechanisms play a minor role in range effect tendencies. The range effect is probably related to encoding and comparison processes (Wilberg & Girouard, 1976). It may be that the stage for the comparison

between the reproduction and criterion movements may be subject to change over trials with the result being the overshooting of short distances and the undershooting of long distances.

It was hypothesized in this experiment that if the range effect is related to encoding and comparison processes, the method of presentation of the criterion distances should not alter the appearance of the range effects. The present results lend support to this hypothesis. Reproduction of visually presented criterion distances demonstrated the overshooting of the short distance and the undershooting of the long distance. Therefore, provided accurate encoding of movement distance information is possible, it would appear that the locus of the range effect may be the comparator stage for the criterion and reproduction movements. If a comparison between criterion and reproduction distances is made difficult by the presentation of conflicting criterion movement information, then the tendencies associated with the range effect can be altered (Annett, 1970; Wilberg & Girouard, 1975).

In Experiment 2 it was shown that a large number of trials is usually required for subjects to determine the experimental movement range and produce the characteristic central tendencies of the range effect. These central tendencies were present after only five trials in the present experiment, as shown in Figure 3. Moreover, variable error was lower for both short and long distances in this experiment than in Experiment 2. This indicates that the central tendencies developed in the present experiment were more stable than those produced in Experiment 2. The rapid onset and greater stability of the range effect tendencies in this experiment is probably a result of the

visual presentation of the criterion distance. Subjects reported being able to ascertain the range of movement after only a few trials and usually this is not possible when criterion movements are kinesthetically presented.

Experiment 5

Encoding and Response Strategies for Distance

While there appears to be a great deal of coding flexibility in motor memory (Marteniuk, 1975), research has produced considerable knowledge concerning how individuals actively manipulate input information for the purpose of storing it in memory, and recognizing or recalling it either immediately or following a short retention period. Distance and location information are both reproduced more accurately when they are actively rather than passively presented (Marteniuk, 1973; Jones, 1974). The usual interpretation given to this finding is that efferent information about where a limb will be moved is more reliable and useful than information about where a limb has gone. Efferent information refers to information arising from the initial movement command as this command leaves the higher nervous centers and travels to the muscles. Efference copy can be considered as a stored representation of prior sensory consequences (Adams, 1971).

Preselection of a movement is another input variable that has been the subject of recent investigation. Jones (1974) contends that when a subject is allowed to voluntarily preselect a movement the efference copy is centrally monitored. Under constrained movement conditions (for example, an experimenter defined stop) the subject has no prior knowledge of the movement extent and the efferent commands initiated cannot provide an accurate efference copy. Hence, reproduction performance decreases as a result of monitoring a less precise efferent output. Stelmach, Kelso and Wallace (1976) generally support the findings of Jones (1974) for the superiority of preselected movements over constrained movements. They suggest, however, that the

superiority of preselected reproduction may simply be because subject-defined movements are more natural to the subject who makes them, or preselection facilitates the encoding of proprioceptive information similar to the concept of corollary discharge in the nervous system.

The presentation of instructions related to the encoding of movement information may also be an important input variable altering performance on a reproduction task. Movement reproduction accuracy seems to improve when the subjects are given instructions about the relationship among movement stimuli and can implement appropriate reproduction strategies (Nascon, Jaeger & Gentile, 1972). In contrast, instructions to focus on the kinesthetic sensations of a movement are not effective as an encoding strategy (Gomez-Toussaint & Chevalier-Girard, 1975). One of the purposes of the present study was to look at the effect of varying the position of the reproduction instructions with respect to the presentation of the criterion distance. Instructions as to the type of reproduction required on a trial were given before or after the presentation of the criterion movement.

Subjects may actively manipulate their responses and these changes can also have a large influence on reproduction performance. Response strategies employed by subjects in short-term motor memory experiments, however, have not received much consideration in the past. In the present experiment the strategies associated with the bracketing paradigm (Buckolz, 1974) were employed. These response strategies were used since subjects demonstrated the ability to successfully apply bracketing response strategies to distance reproduction in Experiment 1. Therefore, the second purpose of this experiment was to examine in more detail the affect of bracketing responses on distance reproduction.

Method

Subjects

The subjects were the same as those who participated in Experiment 2.

Apparatus and Task

The apparatus and task were identical to the ones employed in the second experiment.

Design

The experimental design was a 2 x 2 x 3 factorial with repeated measures on all factors. The first factor was two levels of movement distance, short (5.0 cm) and long (25.0 cm). The second factor was two levels of instruction presentation: instructions for the type of response strategy to be employed in reproducing the criterion distance was given to the subject either before or after the presentation of the criterion distance. The third factor was three levels of response strategy: reproduction of a distance just less than (1 jnd) the criterion distance, accurate reproduction of a distance, reproduction of a distance just greater than the criterion distance. Experiment 2 acted as the control condition for the response strategy conditions of the present experiment. Each subject received 90 trials, the experimental conditions being randomly distributed over trials.

Procedure

The general procedure was the same as in Experiment 2 with the following exceptions. On each trial the subject had one of three possible response strategies to execute. The instructions as to which

type of response strategy to follow were given to the subject just prior to the presentation of the criterion distance, or as the cursor was being repositioned for the distance reproduction. The instructions were simple two word phrases. Therefore, on each trial the subject was presented a criterion distance and required to produce the appropriate response; a movement *greater than* the criterion, *equal to* the criterion or *less than* the criterion.

The initial instructions stressed the importance of performing the required response strategy to the best of the subject's ability, thereby hopefully eliminating any tendency to overcompensate in the just less than and just greater than conditions.

Data Analysis

The error scores examined were similar to those utilized in the previous experiments. The frequency of the CE scores were plotted for the short and long distances.

Results

Movement distance for CE was significant in the present experiment, $F(1,105) = 25.63$, $p<.01$. The short distance (5.86 mm) demonstrated the overshooting tendency and the long distance (-4.92 mm) the undershooting tendency. Response strategy for CE also proved to be significant, $F(2,140) = 91.42$, $p<.01$. Further analysis with the Scheffé test indicated that the three response strategies of *less than* (-18.48 mm), *equal to* (0.56 mm), and *greater than* (24.13 mm) were significantly different from each other. Response strategy was also significant for AE, $F(2,140) = 4.57$. With the Scheffé test it was found that the *greater than* (30.33 mm) and *equal to* (24.13 mm) conditions were significantly different ($p<.05$), but that the *less than* condition (27.55 mm) did not differ from the other two. Response strategy for VE and AV failed to demonstrate significance ($p>.05$). As shown in Figure 4, the movement distance by response strategy interaction was significant for CE, $F(92,140) = 15.74$, $p<.01$. While a gradual CE-shift from undershooting to overshooting occurs for the short movement lengths over the corresponding response strategy conditions, there is a large positive CE-shift for the long movement lengths between the accurate and greater than response strategies. The movement distance by response strategy interaction was also significant for AE, $F(2,140) = 13.28$, $p<.01$ and AV, $F(2,140) = 3.59$, $p<.05$. Again a difference between short and long distances for the response strategies was evident. Instruction presentation for CE and AV failed to reach the conventional level of significance ($p>.05$). For AE instruction presentation was significant, $F(1,105) = 6.78$, $p<.05$. The same pattern of results was

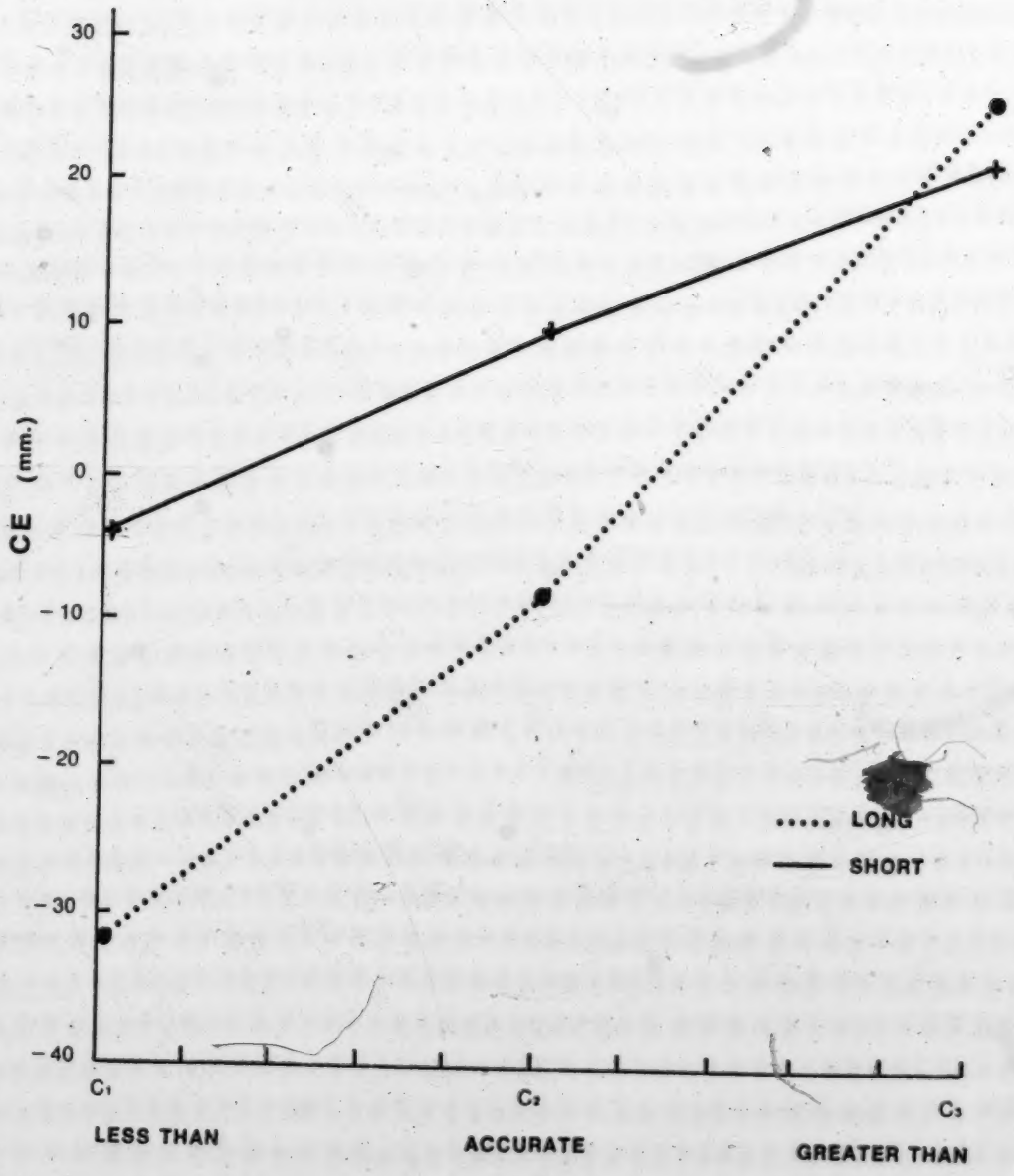

Figure 4. The interaction between movement distance and response strategy for CE.

found for VE, $F(1,105) = 5.54$, $p<.05$. In both cases instructions before the criterion distance (AE = 24.99 mm; VE = 21.97 mm) resulted in a better performance than instructions following the criterion distance (AE = 29.67 mm; VE = 27.56 mm).

In order to obtain a clear understanding of the relationship between movement distance and response strategy, the distributions of the error scores for the three response strategies for both the short and long distances were investigated. The three response strategy distributions for the short movement distances were found to be very similar with the scores being concentrated around the subject-determined zero point for each strategy. The distributions for the long movement distances were very different for each response strategy and characterized by a wider dispersion of scores. The response strategies of CE for the short movement distance appear in Figure 5 and those for the long movement distance are shown in Figure 6.

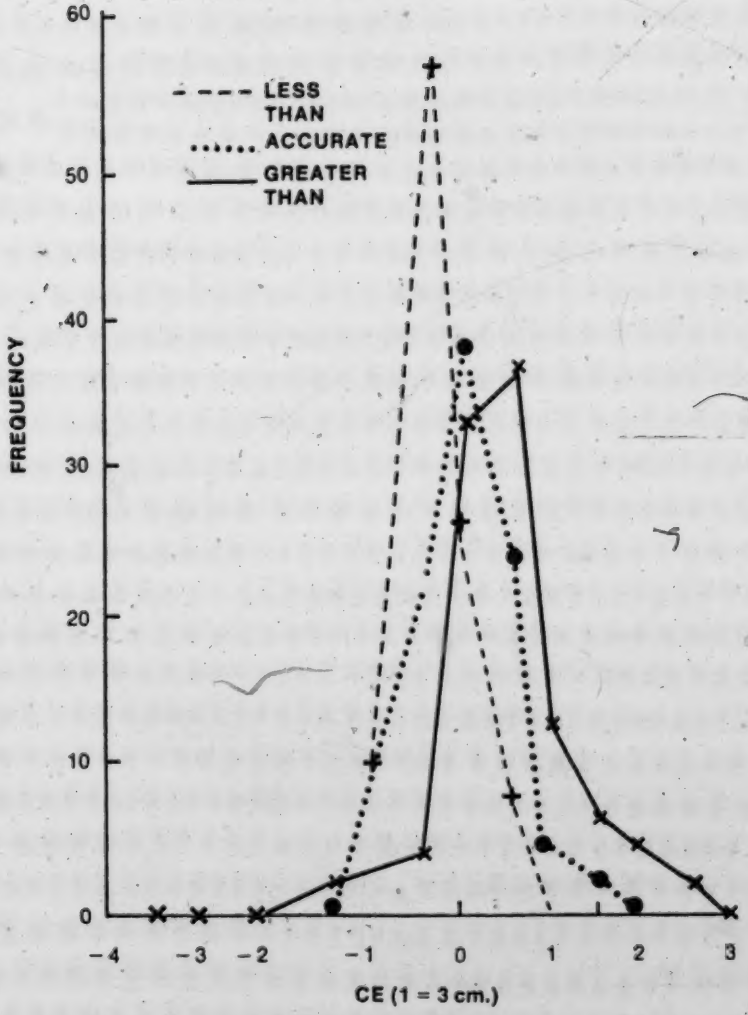

Figure 5. Distribution of CE scores of the short movement length for the response strategy conditions.

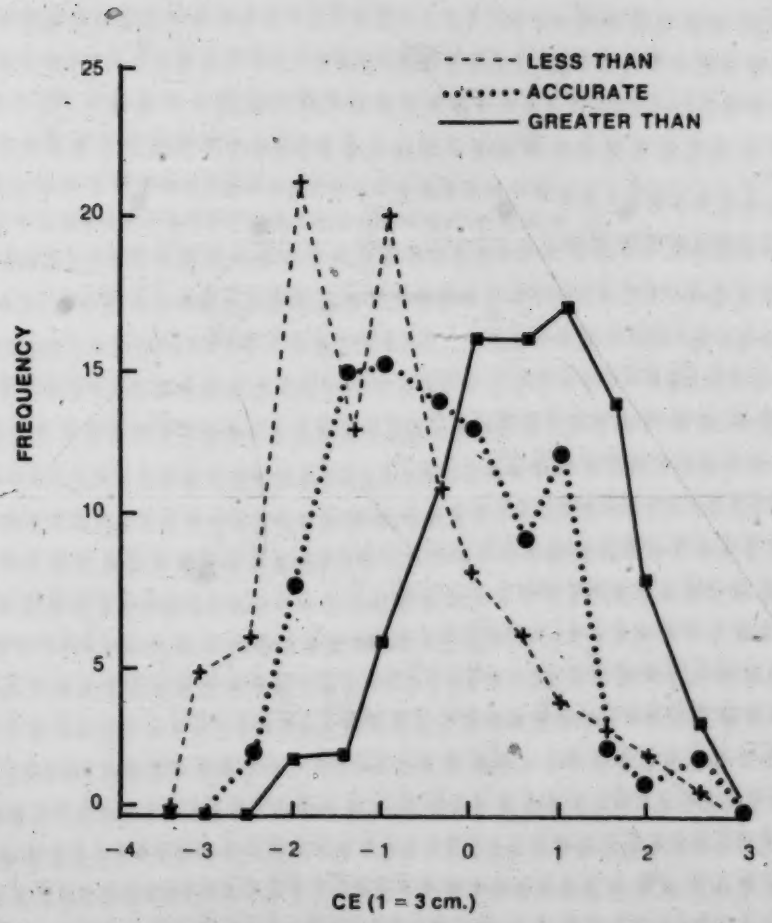

Figure 6. Distribution of CE scores of the long movement length for the response strategy conditions.

Discussion

A comparison of Experiment 2 and Experiment 5 reveals similar performance patterns for movement distance. There is a tendency for short distances to be overshot and long distances to be undershot for accurate reproduction of the criterion distances. The most important result of this comparison is that the range effect appears to be independent of instruction presentation and response strategy as defined in the present research. In addition, movement distance reproduction performance in the present experiment appears to be better if the response strategy instructions are given before, rather than following the presentation of the criterion distance. Presenting the instructions before the criterion distance probably facilitates the encoding of information into some type of framework that is utilized for making the reproductions. This may be similar to elaboration as discussed by Bower (1972). When the instructions for the reproduction are presented following the criterion movement the type of coding involved may be reconstructive (Ellis, 1973).

Subjects were able to produce the required response strategies indicating that response strategy formation can supercede the central tendencies associated with the range effect. Subjects can be under-estimators or over-estimators, and tendencies in distance recall data that appear to correspond with range effect tendencies may be due to the response strategies adopted by the subjects.

The distributions for the error scores provide some indication of how subjects approached the task of distance reproduction for the various response strategies. When reproducing short distances, subjects appear to have approached the task in much the same manner

regardless of the type of response strategy being employed. The somewhat decreased variable performance for the *less than* condition suggests subjects were better able to establish, and consistently incorporate in their response strategy, a zero point when making reproductions under this condition. With respect to long distances, the three different distributions suggest the subjects approached the task of distance reproduction in a separate manner for each response strategy. Finally, there is a definite difference between the nature of reproductions for short and long distances regardless of strategy.

Experiment 6

Distance Reproduction, Velocity and the Range Effect

The previous experiments in this series have examined the reproduction of movement distance focusing primarily on a characteristic referred to as the range effect, the tendency to overshoot short distances and undershoot long distances. Short distances were shown to be more accurately (AE) reproduced than long distances, corresponding with previous research (Laabs, 1973). The central tendencies of the range effect appeared to be relatively a stable characteristic of distance reproduction; nevertheless, these performance patterns are general descriptors and not very useful in attempting to predict individual performance. An analysis of the distribution of the error scores for these tendencies over various reproduction strategies indicated a difference between the nature of the reproductions for short and long distances. In an endeavour to understand these differences it was decided in the present experiment to investigate the reproduction of distance over time, which reduces to a time-dependent variable such as velocity.

Although the correlation of displacement with time has been recognized as an important attribute for movement reproduction (Tomlinson, 1972), research has generally been concerned with other types of movement information. Time-dependent variables have usually been examined within the context of movement control. Woodworth (1899) conducted much of the early work in this area and found speed of movement has little influence on movement accuracy. He also reported that faster speeds result in movements longer than a criterion and slower speeds in movements shorter than a criterion. Bahrick, Fitts and Schneider

(1955), examining the reproduction of simple triangular and circular movements with a control stick, showed that damping (increased torque) and increased mass facilitates rate and acceleration discriminations. In addition, Fuchs (1962) demonstrated that with practice trials subjects progressively utilize velocity and acceleration information in producing controlled responses.

There is also considerable data on the movement of a hand towards a target. An acceleration phase, a central phase of uniform velocity and a deceleration phase in movements of this type was distinquished by Woodworth (1899). Several researchers (Taylor, 1947; Taylor & Birmingham, 1948; Vince, 1948) have concluded, however, that there is no period of constant velocity in approach movements. Furthermore, the relative sizes of the acceleration and deceleration phases seems to depend on terminal accuracy. Movements of an approximate extent have symmetrical patterns while accurate movements tended to have longer deceleration phases (Taylor, 1947; Taylor & Birmingham, 1948; Edwards, 1965). Recently it has been demonstrated that symmetrical approach curves are produced for accurate movements if high movement speeds or naive subjects are tested (Howarth, Beggs & Bowden, 1971; Beggs & Howarth, 1972). With practiced subjects most of the movement time is spent close to the targets. The approach involves a fast movement to the target area followed by a slow terminal phase (Annett, Golby & Kay, 1958; Beggs & Howarth, 1972). The accuracy of movements to a target with vision eliminated has been shown to be linearly related to distance and also affected by movement speed (Beggs, Andrew, Baker, Dove, Fairclough & Howarth, 1972).

In research more directly related to movement reproduction based on time-dependent attributes, Marteniuk, Shields and Campbell (1972) found that subjects used the same relative velocity of movement for both criterion and reproduction movements. Correlations between error scores for movement reproduction and average velocity of the criterion and reproduction movements were very low. A similar pattern of results was found for timing accuracy (measured by the mean difference limens of time reproduction). Therefore, it was concluded that velocity and timing ability play a minor role in movement reproduction.

Method

Subjects

The subjects once more were six student volunteers at the University of Alberta. Each subject was paid $2.00 per hour for their participation. The only participation requirement was that subjects wrote with their right hand.

Apparatus and Task

A meter bar (uncalibrated) mounted on a dexion frame served as the track on which linear movement distances were produced by the subjects. The subjects made these lengths by moving a plastic cursor with a metal handle. The cursor was attached to a 10-turn potentiometer whose output, after being passed through a voltage divider/amplifier box, was connected to a digital multimeter (Fluke 8000A) and a XYY' recorder (Honeywell 514). Therefore, when the cursor was moved, the distance traversed was recorded by a change in the digital output of the multimeter. In addition, the distance moved was plotted on the XYY' recorder against a time base (0.5 cm./sec.). Thd digital output of the multimeter was in mv and the voltage divider/amplifier box was set at a constant value (1:1 ratio) throughout the experiment.

The subject sat comfortably in front of the apparatus wearing a blindfold and moved the cursor horizontally from the left to right with the right hand. The range employed on the meter bar was a maximum of 65.0 cm, all distances being made within that range. Mounted adjacent to the track on the dexion frame was a plastic distance marker, calibrated in mm, and a metal bar with a moveable wooden stop. The stop was utilized in the presentation of the criterion distances.

Design

The experiment consisted of a single treatment factor, movement distance, with two levels: short (5.0 cm) and long (25.0 cm). Subjects received 15 trials for each of the randomly presented distances. At the termination of the testing the subjects were given a questionnaire concerning the distances employed in the experiment and the types of reproduction strategies they implemented.

Procedure

On each trial the subject reproduced the criterion distance, location information being made irrelevant with the use of 6 different starting positions. The criterion distance was presented by having the subject move the cursor until contacting the physical stop. The cursor was then repositioned to a new starting position and the subject attempted to accurately reproduce the criterion distance. After the reproduction, the distance was recorded to the nearest mm.

Data Analysis

The four dependent measures examined in the previous experiments were employed in the present experiment; CE, VE, AE and AV. Velocity, acceleration and deceleration for the criterion and reproduction distances were calculated.

Results

As reported in previous range effect experiments CE for movement distance was significant, $F(1,89) = 4.28$, $p<.05$. All subjects demonstrated the tendency to overshoot the short distance (3.0 mm) and, with one exception, all subjects produced the typical undershooting of the long distance (-4.0 mm). VE was also significant, $F(1,89) = 5.87$, $p<.05$, the reproduction of the short distance (10.0 mm) being less variable than the long distance (40.0 mm).

For AE and AV a similar pattern of results was found. The short distance was associated with a significantly smaller AE (10.0 mm) than the long distance (36.0 mm), $F(1,89) = 107.15$, $p<.01$. In addition, AV for the short distance (7.0 mm) was considerably less than for the long distance (23.0 mm), $F(1,89) = 5.76$, $p<.05$.

The average velocity, acceleration over the initial 0.5 seconds, and deceleration over the final 0.5 seconds of the short distance condition were not significantly different for the criterion and reproduction movements ($p<.05$). The average velocity curves for the short distance are shown in Figure 7. Average velocity and acceleration (over the first second) also failed to be significantly different for the criterion and reproduction movements of the long distance condition, ($p>.05$). However, deceleration over the last second of the movement was significantly different for the criterion and reproduction movements, $F(1,45) = 7.74$, $p<.01$. The average deceleration for the criterion movement was 2.5 cm/sec/sec and for the reproduction movement 2.0 cm/sec/sec. The average duration for the production of the long distance was 7.0 seconds. The average curves for the long distance are shown in Figure 8.

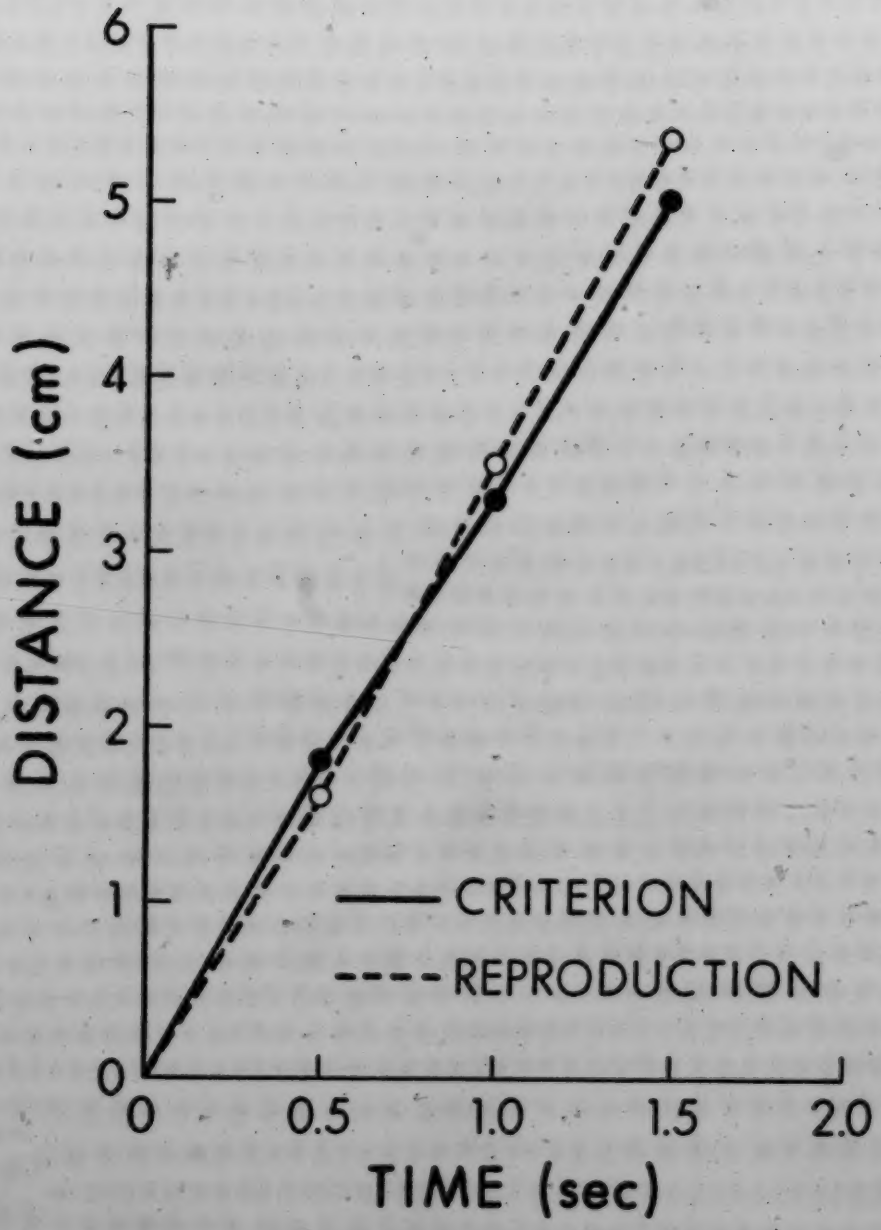

Figure 7. Average velocity curves for the short distance (5.0 cm).

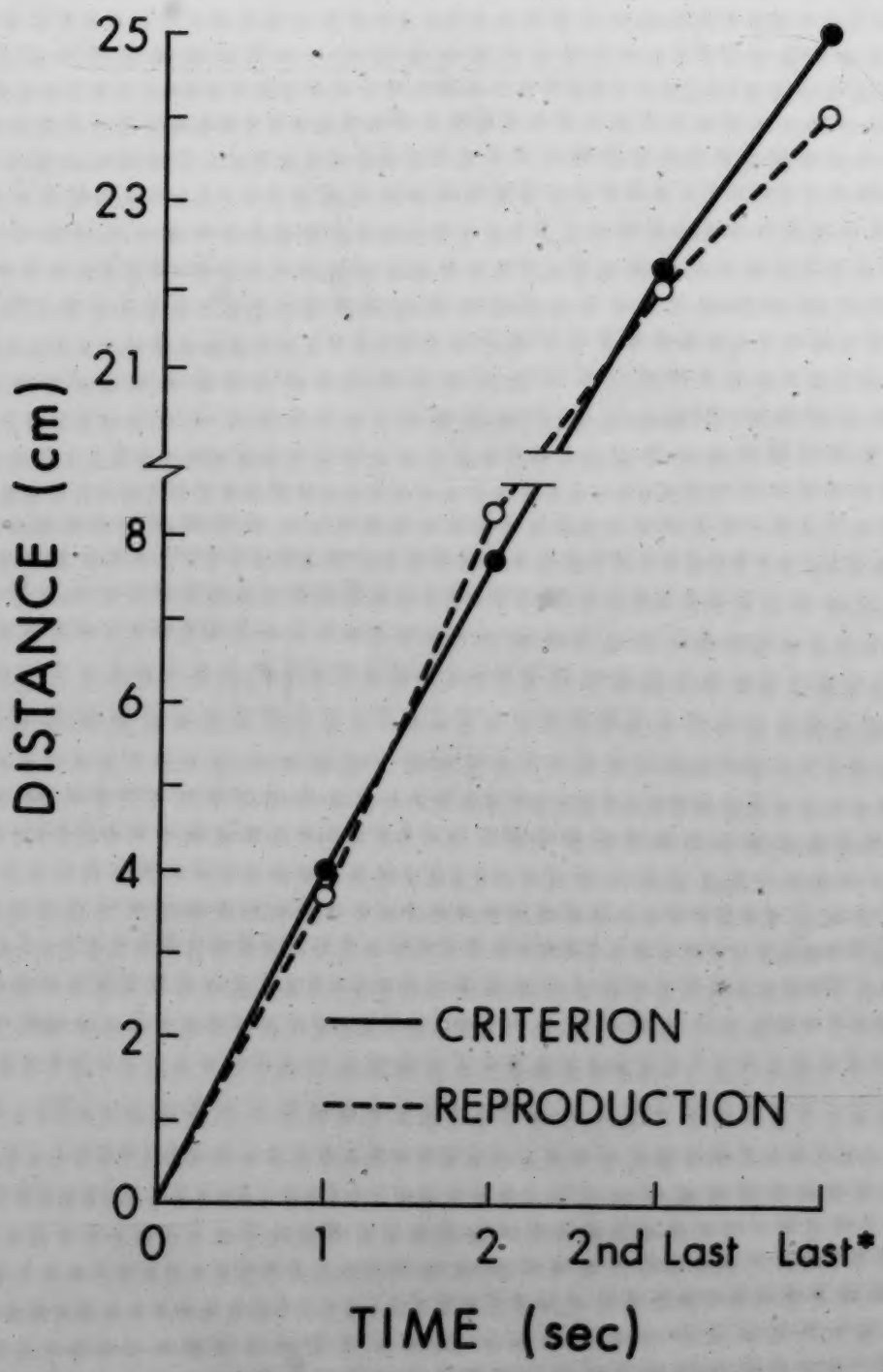

Figure 8. Average velocity curves for the long distance (25.0 cm).

* The average duration for the long distance was 7.0 sec.

A comparison between the short and long distance conditions revealed very similar average velocities. There was, however, a difference between the average acceleration, $F(1,45) = 12.94$, $p<.01$, and average deceleration, $F(1,45) = 13.05$, $p<.01$, for the reproduction of the short and long distances. An order effect for the rate of deceleration was found for reproductions of the long distance, the average deceleration over the final second of the movement being 2.5 cm/sec/sec for the first five trials and 1.8 cm/sec/sec for the last five trials. Correlations between the average velocities for the various short and long distance conditions were very high ranging from +0.82 to +0.98, but the correlations for these average velocities with the different error scores were quite low, -0.44 to +0.03. The only exceptions were moderately high negative correlations between CE - AE for the long distance and the average velocities for the criterion and reproduction long movements, -0.58 to -0.70.

In order to completely investigate the central tendencies of the range effect the criterion and reproduction movements were divided into three sections. The initial 0.5 sec of a short move and 1.0 sec of a long move were designated as section A. The last 0.5 sec of a short move and 1.0 sec of a long move were designated as section C. The middle portion of the move was considered to be section B. The correlations between the average velocities of the three sections for the short movements and the various error scores for the short distance ranged from -0.53 to +0.29. Only slightly higher correlations were found between the average velocities of the sections for the long movements and the error scores for the long distance, -0.72 to +0.63.

The correlations of greatest interest were between the respective movement section distances for the criterion and reproduction moves. For sections A and C of the criterion and reproduction movements for both distances the correlations were from +0.90 to +0.97. For the B section of the criterion and reproduction movements for the short distance the correlation was +0.74, the middle section of the reproduction movement being longer (+2.5 mm) than that of the criterion movement. The correlation between the B section of the criterion and reproduction movements for the long distance was +0.75. For those subjects demonstrating an undershooting of the long criterion distance there was a slight decrease in the middle section of the reproduction movement compared to the middle section of the criterion movement (1.9 mm). The subject who failed to develop the range effect for the long distance constantly made the B section of the reproduction movement greater than the B section of the criterion movement.

When subjects were given a post-experiment questionnaire concerning the type of strategy they employed for making the reproductions their preference was for counting while attempting to maintain a constant rate of movement with the cursor. The same reproduction strategy was utilized for both short and long distance. The number of different criterion lengths utilized in the experiment was generally estimated to be three or four, the subjects reporting the inclusion of some "medium" distances.

Discussion

The results of previous research (Experiments 1, 2, 5) on the range effect were replicated in the present experiment. Several prominent findings warrent mentioning. Long distances are not as accurately and precisely reproduced as short distances, and the undershooting tendency for long distances takes more practice to develop and is a less stable characteristic of distance reproduction than the overshooting tendency for short distances. In addition, the performance patterns described by the range effect should be considered as general descriptors and may not be useful in attempting to predict individual performance.

The criterion and reproduction movements were shown to be similar with respect to average velocity, corresponding with Marteniuk, Sheilds and Campbell (1972). There was also no difference between criterion and reproduction movements for the acceleration and deceleration phases in the short distance condition. Since velocity of movement correlated poorly with the accuracy and precision of movement reproductions it would appear, as previously reported (Woodworth, 1899; Marteniuk, Shields & Campbell, 1972), that movement velocity has little influence on movement accuracy and precision in movement reproduction tasks. Moreover, this finding can be extended when the relationships between the various sections (A, B, and C) of the criterion and reproduction movements are examined. While there were rather low correlations between the average movement velocities of the different movement sections and the accuracy of the reproductions, the respective sections of the criterion and reproduction movements were highly related in terms of average velocity.

In the previous experiments it was suggested that short and long distances may be dealt with differently during a reproduction task. A comparison between the short and long distances in the present study indicates that there is little difference in the way they are handled when accurate distance reproductions are being made. There was some difference in the average rate of acceleration and deceleration for the reproduction of the two distances, but no difference in the velocity of movement. Furthermore, the respective sections of the movements for the two distances were highly correlated. Finally, although subject introspection may be suspect, subjects reported utilizing the same counting strategy for the reproduction of the short and long distances.

There have been various studies (Taylor, 1947; Vince, 1948) demonstrating there is no period of constant velocity in movements to a target. A constant velocity stage was evident in the present experiment for both criterion and reproduction movements; however, movements in this experiment were to a physical stop and a subject determined end-point, and not a target. Vision was also eliminated in the present experiment whereas movement accuracy studies generally involve a visual component. Comparing the various phases with respect to duration was not possible in this experiment since the durations of the three phases (A,B,C) were experimenter defined. Moreover, a deceleration phase may be absent in criterion movements made to a physical stop (Bahrick, Fitts & Schneider, 1955) making such comparisons difficult unless subjects anticipate the location of the stop, and this may have been the case for the long distance in the present experiment.

With practice subjects tend to utilize time-dependent information in producing controlled responses (Bahrick, Fitts and Schneider, 1955; Fuchs, 1962). The high correlations between the corresponding movement sections for the criterion and reproduction movements indicates subjects were using acceleration and velocity information during the task in the present study. More importantly, the relationship of the criterion and reproduction movement sections, especially with respect to distance, suggests a locus for the performance patterns associated with the range effect. When reproducing short distances subjects tend to increase the middle (B) section of the movement. This would account for the general overshooting of short distances when making accurate distance reproductions. For the long distances, the characteristic undershooting appears to be a result of the interaction between the middle and final (C) sections of the movement. Usually the middle section of the criterion and reproduction movements are approximately the same length, but over trials the middle section of the reproduction movement tends to decrease in length as compared to the criterion movement. Generally the final section of the reproduction movement also shows some reduction in length thus augmenting the range effect. For those cases in which the typical undershooting of long distances is not evidenced, the middle section of the reproduction movement seems to be increased in length. This effectively counters any decrease in length of the final section of the movement that may develop.

Experiment 7

Distance Reproduction, Velocity and Response Strategy

The reproduction of a set of distances tends to produce the performance patterns referred to as the range effect (Pepper & Herman, 1970; Laabs, 1973). In the present series of experiments it has been shown that the range effect takes time to develop and develops unequally fast in short (5.0 cm) and long (25.0 cm) movements. For short movements the overshooting tendency is demonstrated within a few trials but the undershooting tendency for long movements may not appear until after thirty or more trials. Both Buckolz (1974) and the present research have demonstrated that the central tendencies associated with the range effect may simply be due to the response strategies adopted by the subject. Response strategies refer to subjects deliberate over-estimation and under-estimation of reproduction items, including time and distance. Response strategy formation in such instances supercedes any range effect tendencies.

The bracketing paradigm utilized in the previous experiments to investigate response strategy formation for movement distance indicated several reproduction characteristics. Subjects varied their approach to the reproduction of distance depending upon both the response strategy and distance employed. Response strategy (over-estimation or under-estimation) did not differentially influence the task in the reproduction of short distances. It appeared, however, in the reproduction of long distances that subjects handled the task in a separate manner for each response strategy. There was also a definite difference between how subjects approached the task of reproducing short and long distances, regardless of strategy.

The previous bracketing experiments investigating response strategies considered error scores (algebraic, absolute, and variable error) and the distributions of these scores. To gain further insight into the differences occuring in distance reproduction with the implimentation of various response strategies, the present experiment attempts to extend previous findings by examining the distance/time component for movements produced using different strategies. This time component reduces to a time-dependent variable such as velocity.

Method

Subjects

The subjects were 6 students from the University of Alberta who were paid at a rate of $2.00 per hour. The only participation requirement was that subjects wrote with their right hand.

Apparatus and Task

The apparatus and task were the same apparatus and task as employed in Experiment 6.

Design

The experimental design was a 2 x 3 factorial with repeated measures on both factors. The first factor consisted of two levels of movement distance, short (5.0 cm) and long 25.0 cm). The second factor, response strategy, consisted of three levels: reproduction of a distance just less than the criterion distance (1 jnd), accurate reproduction of the criterion distance, and reproduction of a distance just greater than the criterion distance Each subject received 10 trials on each treatment condition and the total of 60 trials were randomly presented.

Procedure

The criterion distance was presented by having the subject move the cursor until contacting the physical stop. The cursor was then repositioned to a new starting position and the subject attempted to reproduce the criterion distance according to the appropriate response strategy. Location information was made irrelevant with the use of 6

different starting positions. The instructions as to which type of response strategy to produce were given to the subject just prior to the presentation of the criterion distance. The instructions were simple two word phrases (*less than, equal to* or *greater than*).

Data Analysis

Algebraic error (CE), variable error (VE), absolute error (AE), and average variation (AV) were each submitted to a separate analysis of variance. Velocity (cm/sec) for the criterion and reproduction distances was also calculated.

Results

The results obtained in the previous experiments for the various error scores were replicated in the present experiment. Short distances were overshot (5.80 mm) and long distances were undershot (-1.71 mm), $F(1,135) = 5.05$, $p<.05$. AE was also significant for movement distance, $F(1,135) = 32.25$, $p<.01$, the short distance (14.69 mm) being more accurately reproduced than the long distance (30.46 mm).[1] There was less variation in the reproduction of the short distance than the long distance. For the short and long distances VE was 14.38 mm and 30.41 mm, $F(1,135) = 19.75$, $p<.01$, and AV was 12.46 mm and 23.47 mm, $F(1,135) = 16.53$, $p<.01$, respectively. CE for response strategy was significant, $F(2,135) = 10.30$, $p<.01$, the values being -11.13 mm for the *less than* strategy, 6.43 mm for accurate reproduction, and 15.73 mm for the *greater than* strategy. It was indicated by further analysis with the Scheffé test that the three response strategies were significantly different ($p<.01$). AE for response strategy demonstrated a similar pattern, $F(1,135) = 4.95$, $p<.05$. The Scheffé test indicated that the *less than* strategy (20.02 mm) was significantly different from the *greater than* strategy (28.03 mm) while the accurate reproduction strategy (25.70 mm) assumed an intermediate value ($p<.05$). Response strategy for VE and AV failed to reach significance as did all the interactions ($p>.05$).

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[1] Although average error is actually a smaller proportion of the long distance (.12) than the short distance (.29) CE and AE are the appropriate indicators of reproduction accuracy in the present experiment since distance reproduction characteristics are being examined, not perceptual/memory functions.

In order to fully analyze the differences in response strategies the criterion and reproduction movements were divided into three sections. The initial 0.5 sec of a short move and 2.0 sec of a long move were designated as section A. The last 0.5 sec of a short move and 2.0 sec of a long move were designated as section C. The middle portion of the move was considered to be section B.

Average velocities for the various movement sections were calculated and the average velocity curves for the short and long distances are shown in Figure 9 and Figure 10, respectively. For the A and B movement sections the criterion and reproduction average velocities were similar ($p<.05$). There was a significant difference between the criterion and reproduction average velocities for the C section of the movements, $F(1,90) = 16.27$, $p<.01$. The average velocities of the three response strategies failed to reach significance for any of the movement sections ($p>.05$).

Correlations between the average velocities for the two movement distances and the different error scores were −0.03 to +0.64, regardless of response strategy. In contrast, the correlations between the short and long distances for average velocity were much higher +0.95 for the *less than* strategy, +0.91 for the *equal to* strategy, and +0.94 for the *greater than* strategy. Similarly, the response strategies were highly correlated with each other, +0.92 to +0.98. When the average velocities for the movements sections were examined, the short and long distances were correlated with values ranging from +0.80 to +0.96. Moreover, the response strategies followed the same pattern with values of +0.79 to +0.98 over the three movement sections.

Of particular interest were the comparison of the A, B and C

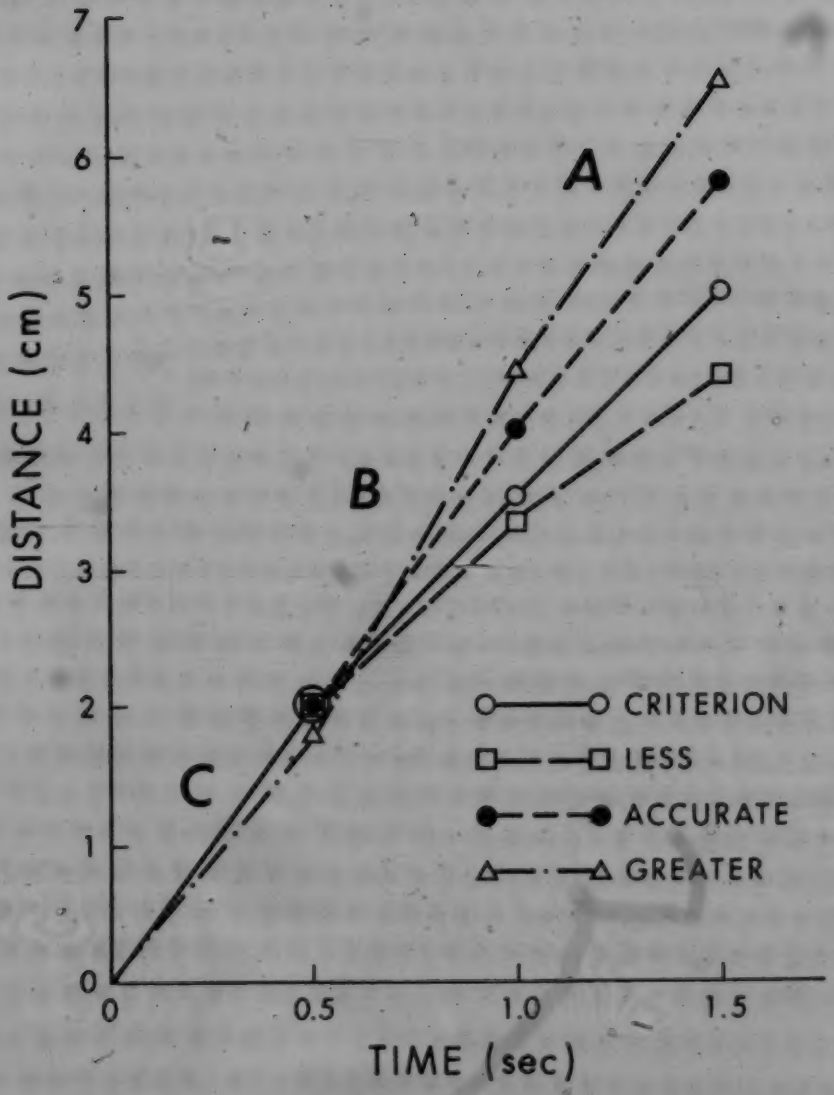


Figure 9. Average velocity curves of the reproduction strategies for the short distance (5.0 cm). A, B and C show the designated average velocity sections of a reproduction movement.

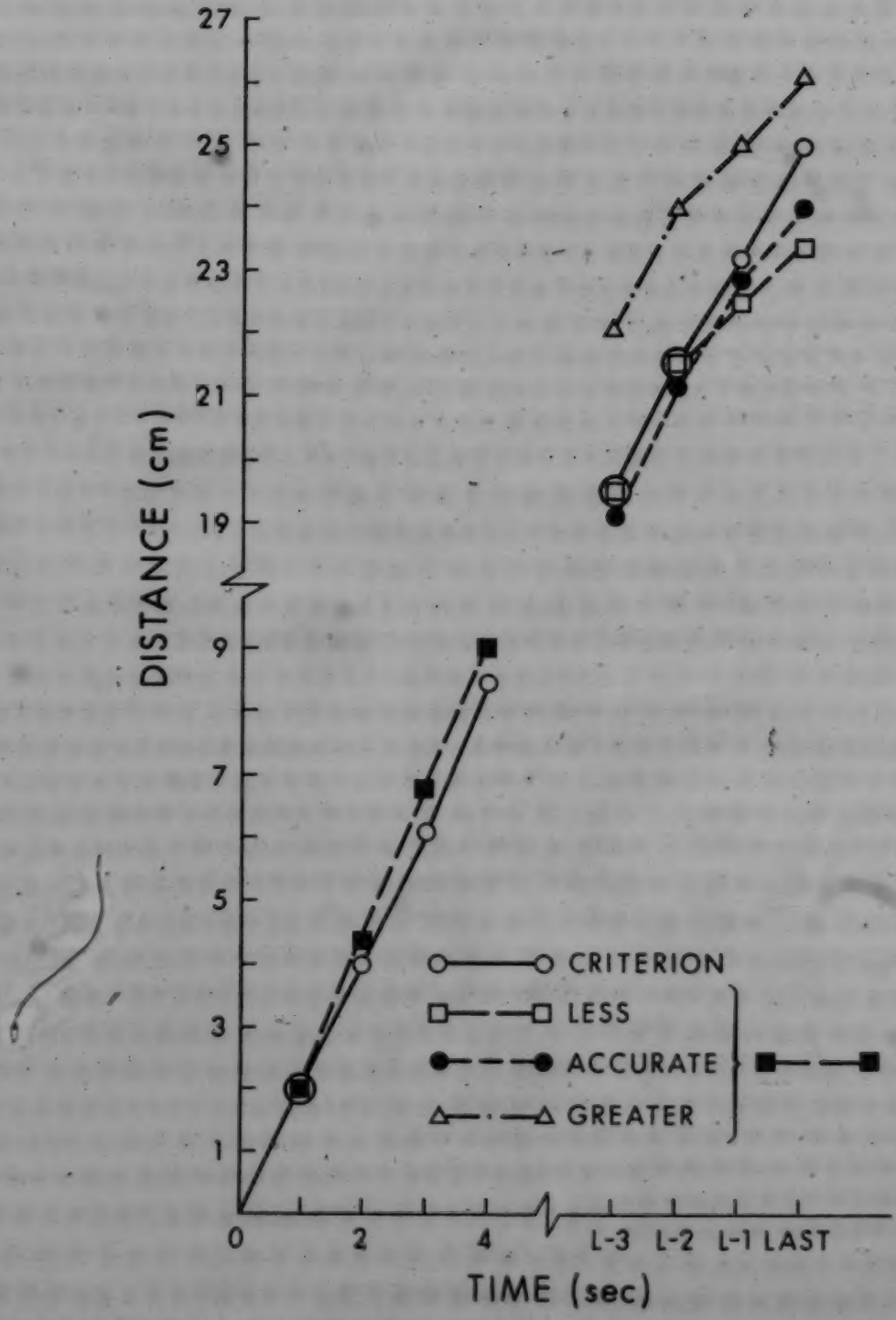


Figure 10. Average velocity curves of the reproduction strategies for the long distance (25.0 cm).

movement sections. For both the short and long distances and over all response strategies the A and C sections were highly correlated for average velocity, +0.92 to +0.98. The correlations for the A and B sections were lower, +0.23 to +0.73, while a comparison of the B anc C sections produced intermediate correlations for the short distance, +0.27 to +0.80, but higher correlations for the long distance, +0.50 to +0.94. The A and C sections of the movements had the lowest correlations with the B section for the *less than* response strategy, +0.23 to +0.50, and the highest correlations for the *greater than* response strategy, +0.62 to +0.94. For all strategies this trend was considerably more evident for the long distance.

The final analysis concerned the distances produced over the A, B and C movement sections for the criterion and reproduction movements. There were no significant differences found for the A section ($p>.05$). The criterion and reproduction movements were significantly different for the B section of the short distance, $F(1,135) = 16.01$, $p<.01$, the differences (CE) for the separate response strategies being -5.1 mm for the less than strategy, 6.0 mm for the accurate strategy, and 9.9 mm for the greater than strategy. A complimentary pattern of results over the response strategies was revealed for the B section of the long distance, $F(1,135) = 4.01$, $p<.05$. The values for the response strategies were -4.2 mm for the *less than* strategy, -1.1 mm for accurate reproduction, and 18.7 mm for the *greater than* strategy. Only for the long distance was there any difference between the criterion and reproduction movements for the C section, $F(1,135) = 9.01$, $p<.01$. The difference values of the three strategies were -3.2 mm for the *less than* strategy, -0.8 mm for the accurate strategy, and -8.4 mm for the *greater than* strategy.

Discussion

Previous experiments (Pepper & Herman, 1970; Laabs, 1973) and this series of experiments have demonstrated that the reproduction of a set of distances tends to produce the range effect; overshooting of short distances and undershooting long distances. The implementation of a "bracketing" response strategy, however, can supercede the central tendencies associated with the range effect. Subjects are capable of purposefully over-estimating or under-estimating distances and may simply adopt response strategies that simulate the tendencies of the range effect. These general conclusions were replicated in the present experiment. In addition, the findings of Marteniuk, Shields and Campbell (1972), that movement velocity has little influence on movement accuracy and precision, were demonstrated. The criterion and reproduction movements were found to be similar with respect to average velocity, but velocity of movement correlated poorly with the accuracy and precision of movement reproductions. These correlations remained low when the relationships between the average velocities of the various movement sections (A, B, and C) and the different error scores were examined.

The primary concern of the present experiment focused on the differences in distance reproductions for the various response strategies. In the reproduction of the short distance the three response strategies were best reflected by the differences of the middle (B) section of the reproductions. For the *less than* strategy the middle section of the reproduction movement was reduced in length compared to the middle section of the criterion movement. The opposite situation tended to

be demonstrated for the *equal to* and *greater than* response strategies. The changes in length of the middle section of these reproduction movements corresponds with the alterations in reproduction length required by the particular response strategy executed. The initial (A) and final (B) sections of the criterion and reproduction movements were highly correlated and appear to play a minor role in differences associated with the various response strategies.

The differences between the response strategies for the long distance seem to be of a more complex nature. The middle section of the reproduction movements varied over strategies in a manner similar to that found for the corresponding reproductions of the short distance. For the *less than* strategy the middle section of the reproduction movement was decreased in length compared to the criterion movement, while for the *greater than* strategy it was extended. Accurate reproduction resulted in some reduction in the length of the middle section. These differences in the middle section of the reproduction movements for the response strategies were confounded, however, with differences in the final (C) sections of these movements. The three response strategies all showed a decrease in length of the final section of the reproduction movement in relationship to the criterion movement. Therefore, at least for those response strategies producing an undershooting tendency of the long distance, this tendency appears to be the consequence of an interaction between the middle and final sections of the reproduction movements, as designated in the present experiment.

It was previously suggested that subjects handle response strategies differently for short and long distances. Furthermore, response

strategies for short distance reproduction appear to be approached in a similar manner while those for long distances are not (Experiment 5). The present experiment supports these conclusions. The reproduction of a short distance primarily involves adjusting the extent of the middle section of the movement to correspond with the requirements of the response strategy. Changes in both the middle and final sections of a movement may interact to produce the desired response strategy in the reproduction of a long distance. Moreover, the amount of interaction between the middle and final movement sections tends to vary with the type of response strategy for a long distance. The middle and final sections are much more highly correlated for the *greater than* response strategy than the *less than* response strategy.

Experiment 8

Distance Reproduction, Velocity and End-Point Control

The reproduction of movement distance over time was examined in Experiment 6 and it was reported that movement velocity has little influence on movement reproduction accuracy and precision. In addition, when the criterion and reproduction movements were divided into three sections (A, B, and C), the respective sections of the criterion and reproduction movements were highly related in terms of average velocity. The relationship of the criterion and reproduction movement sections also suggested how the performance patterns associated with the range effect were produced within a reproduction movement. The overshooting of short distances was due to the extension of the middle (B) section of the reproduction movement. The undershooting of long distances was a result of an interaction between the middle (B) and final (C) reproduction movement sections. Generally both the middle and final sections demonstrated a decrease in length.

These findings of Experiment 6 for movement reproduction were replicated in Experiment 7 and extended to reproductions made utilizing bracketing response strategies. The three response strategies were best reflected by the differences in the middle (B) section of the reproductions for the short distance. The middle section of the reproduction movement was reduced in length for the less than strategy. The opposite trend for the middle section was demonstrated for the accurate and greater than strategies. The middle section of the reproduction movements for the long distance varied over strategies in a complementary manner to those of the short distance. The middle sec-

tion of the reproduction movement was decreased in length for the less than strategy and extended in length for the greater than strategy. Accurate reproduction resulted in some reduction in the length of the middle section. All three response strategies also showed a decrease in length of the final (C) section of the reproduction movement in relationship to the criterion.

The findings of Experiments 6 and 7 indicate that the middle (B) section of a movement reproduction for a short distance and both the middle (B) and final (C) sections of a movement reproduction for a long distance are altered over trials to produce the range effect tendencies and modifications in distance reproductions based on bracketing response strategies. In Experiments 6 and 7, however, the A, B and C movement sections were experimenter defined based on the XY recordings of criterion and reproduction movements. Consequently the A, B and C movement sections were only approximate representations of the positive velocity, constant velocity and negative velocity sections of a movement, respectively. This approximate determination of the three movement sections based on changes in velocity may account for the interaction of the middle (B) and final (C) movement sections for the long distance. One purpose of the present experiment was to accurately determine the acceleration, constant velocity and deceleration phases of the criterion and reproduction movements utilizing more stringent procedures in an endevour to ascertain the nature and development of range effect and response strategy tendencies, and replicate the general findings of Experiments 6 and 7.

In the previous experiments in this series the criterion distance end-point was a physical stop. This factor of end-point can be clas-

sified as a task variable (Adams, 1961) and can influence the reproduction of a distance (Wilberg & Tannis, 1974; Marteniuk, 1975). Wilberg and Tannis (1974) employed four types of end-points: subject determined, physical stop, sound off and sound on. They found that the type of end-point affects the accuracy and precision of distance reproduction, especially for distances exceeding 10 cm. Reproduction was most accurate with the physical stop, while an undershooting tendency was associated with the subject determined end-point and an overshooting tendency was associated with the two auditory end-points. Reproduction was least variable for the subject determined end-point and most variable for the sound on end-point. Wilberg and Tannis also reported that the type of end-point influences the appearance of the range effect. The central tendencies associated with the range effect were only found with criterion movements to a physical stop or with sound on. The second purpose of the present study was to investigate distance reproduction over time when the criterion distance end-point was subject determined, light on, sound on or a physical stop rather than just the latter, which was utilized exclusively in the previous experiments in this series.

Method

Subjects

The subjects were 12 students from the University of Alberta who wrote with their right hand.

Apparatus and Task

A meter bar (uncalibrated) mounted on a dexion frame served as the track on which distances were produced by the subject. A metal cursor with a handle was utilized for making the various distances. The cursor was attached to a 10-turn potentiometer whose output, after being passed through a voltage divider/amplifier box, was connected to both a PDP-11 computer and a Fluke 8000A digital multimeter. Therefore, when the cursor was moved, the distance traversed was recorded by both the computer and multimeter as a change in mv. The duration of the movement (msec) was also recorded by the computer. The internal computer clock monitoring data acquisition was programed for 100 ticks per second.

A Brodgen Challenger CHB 20A amplifier, an Eico audio generator and a speaker were used to produce tones signalling the start of a testing session, the end of a testing session, and the end-point of a criterion movement in the sound on condition. A white light indicated the start of a trial and a red light marked the end-point of a criterion movement in the light on condition. All tone and light signals were computer programed and controlled. Mounted adjacent to the metal track was a second linear slide (wooden) calibrated in mm. Attached to the cursor of this linear slide was a metal bar that extended over the

track on which subjects produced movements. This bar acted as the physical stop for the criterion movements in the appropriate condition.

The subjects sat comfortably in front of the apparatus and moved the cursor from his left to right with the right hand. The subjects' vision of the slide and cursor was blocked by a raised platform that covered the apparatus. Along the edges of this platform was a short fringe cloth. Both the signal lights and speaker were attached to the platform directly in front of the seated subject. The range employed on the meter bar was 60.0 cm so all movements were made within this range.

Design

The design was a 2 x 3 x 4 factorial with repeated measures on all factors. The first factor was movement distance with two levels, short (5.0 cm) and long (25.0 cm). The second factor was response strategy consisting of three levels: reproduction of a distance just less than (1 jnd) the criterion distance, accurate reproduction of the criterion distance, and reproduction of a distance just greater than the criterion distance. The third factor was four levels of criterion movement end-point: subject determined, physical stop, light, and tone. The order of the experimental sessions, categorized according to the type of end-point employed, was randomly ordered over subjects. Within individual sessions random treatment orders were established for the factors of movement distance and response strategy. Each treatment condition was replicated 5 times for each subject.

Procedure

On each trial the criterion distance was presented by having the subject grasp the cursor and move it until reaching the type of end-point being utilized within the experimental session. The subject either determined his own criterion movement end-point, terminated the criterion move when a red light was switched on, terminated the move when a tone came on, or moved until contacting the physical stop. The subject then removed his hand from the cursor and the cursor was re-positioned to a new starting position for the distance reproduction. On a command from the experimenter the subject regrasped the cursor and attempted to reproduce the criterion distance according to the response strategy required on that trial. Six different movement start-point locations were utilized to make location information irrelevant. The instructions as to which type of response strategy to produce were given to the subject just prior to the presentation of the criterion distance. The instructions were simple two word phrases (less than, equal to, or greater than).

For the session in which the subject determined his own criterion distance end-points the subject was first presented with a short (5.0 cm) distance and then a long (25.0 cm) distance by moving to a physical stop. The subject was told these two distances were approximately the lengths he should make his criterion distances during the experimental testing. The subject then produced six short and six long distances. This procedure was repeated three times. Next the experimental testing was initiated with the subject being requested to either produce his short or long criterion distance on a given trial. Regardless of the criterion distance made by the subject on a trial, this acted as the

distance to be reproduced for that trial. The subject was requested to vary his two criterion distances as little as possible over trials.

Data Analysis

Algebraic error (CE), absolute error (AE), variable error (VE) and average variation (AV) were calculated and each submitted to a separate analysis of variance. Velocity (cm/sec) was also computed for both the criterion and reproduction distances and the analysis of variance for velocity included the factor of movement set.

Results

The basic measures of this experiment were the four error scores. Movement distance for CE was significant, $F(1,55) = 24.12$, $p<.01$, the short distance being 3.04 cm and the long distance being 1.13 cm. Response strategy was also significant for CE, $F(2,66) = 33.13$, $p<.01$. Further analysis with the Scheffé test indicated the *less than* condition (-0.68 cm) was significnntly different ($p<.05$) from the *greater than* condition (4.80 cm), but the *equal to* strategy (2.16 cm) was not significantly different from either of the other two conditions ($p>.05$). End-point for CE was also significant, $F(3,77) = 32.63$, $p<.01$. Analysis with the Scheffé test revealed that light (4.38 cm) and tone (4.49 cm) were not significantly different ($p>.05$). A similar situation existed between physical stop (-0.22 cm) and subject determined stop (-0.77). However, both tone and light were significantly different from physical stop and subject determined stop ($p<.05$). No interactions were significant for CE ($p>.05$), but in the three way interaction the central tendencies associated with the range effect were evident. The short dis-

tance was overshot (0.76 cm) and the long distance was undershot (-1.00 cm) for both the subject determined stop and physical stop in the *equal to* response strategy condition The relationships between movement distance, response strategy and end-point for CE are given in Table 2.

Movement distance for AE was significant, $F(1,55) = 5.07$, $p<.01$. The short distance was 3.85 cm and the long distance was 4.67 cm. Response strategy was also significant for AE, $F(2,66) = 36.84$, $p<.01$. The values for the *less than*, *equal to* and *greater than* strategies were 3.47 cm, 3.72 cm and 5.61 cm, respectively. The interaction between movement length and response strategy proved to be significant, $F(2,66) = 5.25$, $p<.01$, with the difference between the short and long distances occurring for the *less than* response strategy. Also significant for AE in this analysis was end-point, $F(3,77) = 14.24$, $p<.01$. AE was greatest for tone (5.40 cm) and light (5.15 cm) and lowest for physical stop (3.50 cm) and subject determined stop (3.02 cm). Both the interactions between movement distance and end-point (Figure 11), $F(3,77) = 7.38$, $p<.01$, and response strategy and end-point, $F(6,110) = 10.02$, $p<.01$, were significant. The three way interaction failed to reach the conventional level of significance ($p>.05$).

The present analysis showed a significant effect of movement distance for VE, $F(1,55) = 14.39$, $p<.01$. As with CE and AE, VE was less for the short distance (1.68 cm) than the long distance (3.85 cm). Also significant in this analysis was response strategy, $F(2,66) = 3.62$, $p<.05$, for VE. Further analysis with the Sheffe test indicated that the *less than* (2.57 cm) and *equal to* (2.69 cm) strategies were similar while the *greater than* strategy (3.71 cm) was significantly higher than both of these other strategies ($p<.05$). End-point failed to be signi-

TABLE 2

The Relationship Between Movement Distance, Response Strategy and End-point for CE

Movement Distance	Response Strategy	End-point			
		Tone	Light	Physical Stop	Subject Determined
Short	Less Than	2.81	2.99	-0.75	-2.47
	Equal To	5.71	5.76	1.58	-0.07
	Greater Than	8.53	7.16	3.29	1.88
Long	Less Than	-0.10	0.54	-3.34	-5.43
	Equal To	3.13	3.21	-1.40	-0.58
	Greater Than	6.87	6.61	1.96	2.06

Values in cm

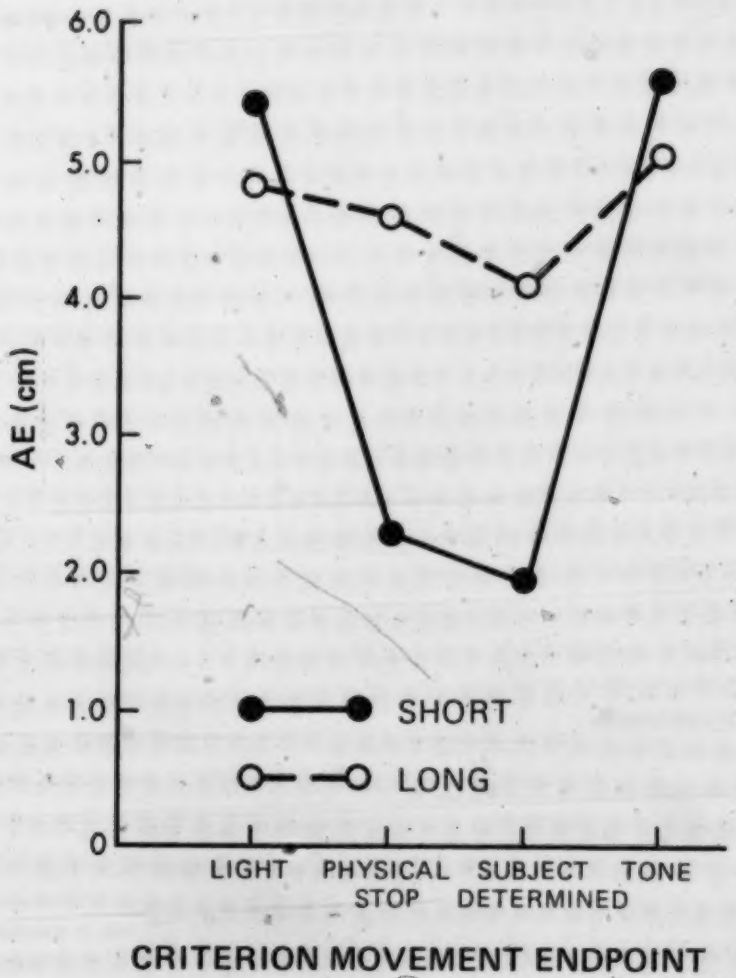


Figure 11. The interaction between movement distance and end-point for AE.

ficant for VE ($p>.05$). The only interaction for VE to reach significance was between movement distance and end-point, $F(3,77) = 13.76$, $p<.01$, and this interaction is illustrated in Figure 12.

Movement distance for AV was significant, $F(1,55) = 34.08$, $p<.01$, with the short distance being 1.59 cm and the long distance being 2.99 cm. Both response strategy and end-point failed to reach the conventional level of significance ($p>.05$). The only interaction that was significant was between movement distance and end-ponnt, $F(3,77) = 4.07$, $p<.05$.

In addition to the error scores, velocity data was also subjected to an analysis of variance. Movement set for velocity was found to be significant, $F(1,55) = 21.06$, $p<.01$, criterion distances being produced faster (9.72 cm/sec) than reproduction distances (7.58 cm/sec). Also significant in this analysis was movement distance, $F(1,55) = 18.55$, $p<.01$. The short distance was made considerably slower (7.81 cm/sec) than the long distance (9.48 cm/sec). The interaction between movement set and movement distance also proved to be significant, $F(1,55) = 19.47$, $p<.01$. The present analysis also showed a significant effect for end-point, $F(3,77) = 9.02$, $p<.01$. Higher velocities were associated with tone (9.49 cm/sec) and light (9.22 cm/sec) while lower velocities were found for physical stop (7.12 cm/sec) and subject-determined stop (8.55 cm/sec). There was an interaction, however, between movement set and end point, $F(3,77) = 18.20$, $p<.01$, as shown in Figure 13. The interaction between movement distance and end-point also was significant, $F(3,77) = 22.80$, $p<.01$. This interaction is depicted in Figure 14. Response strategy for velocity failed to reach the conventional level of significance ($p>.05$) and all other interactions were found to be

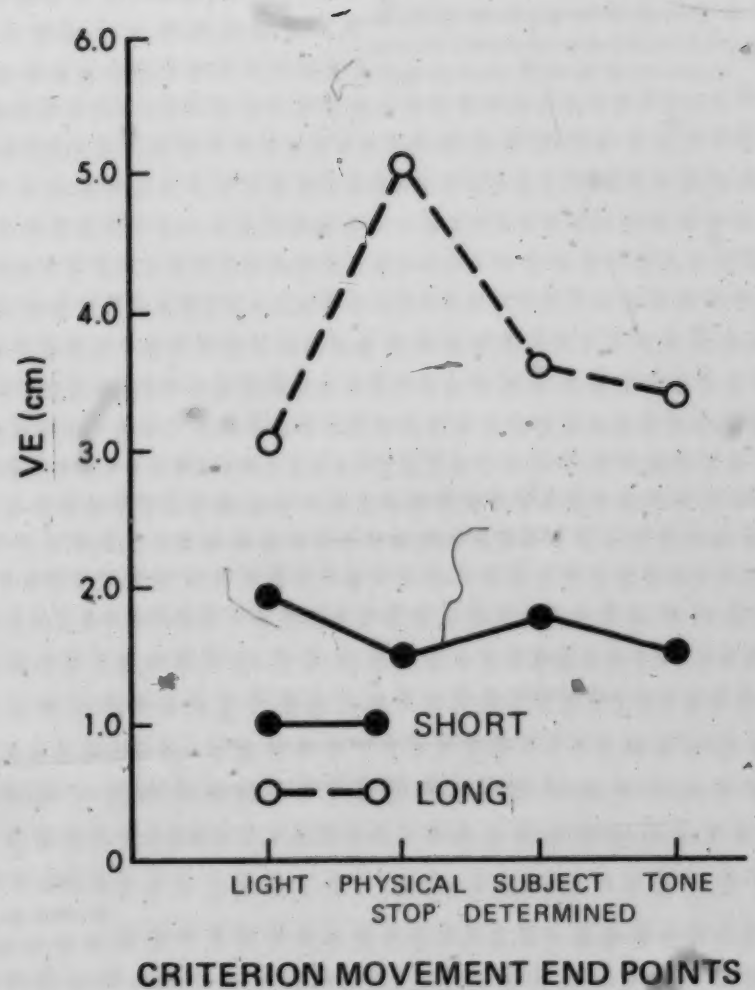


Figure 12. The interaction between movement distance and end-point for VE.

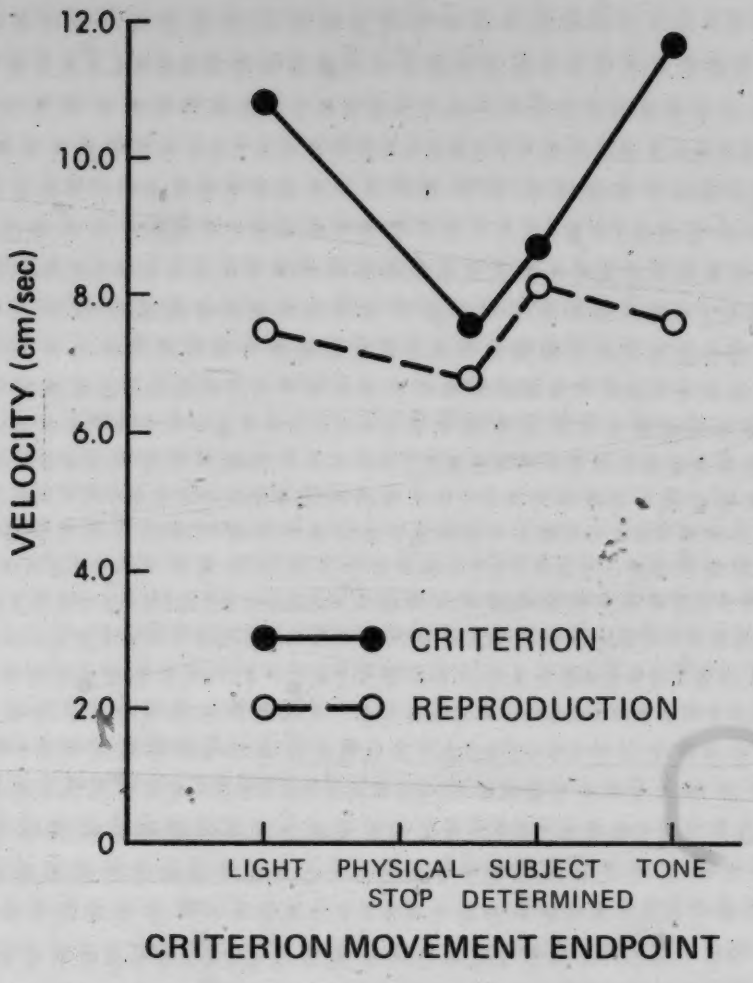


Figure 13. The interaction between movement set and end-point for average velocity.

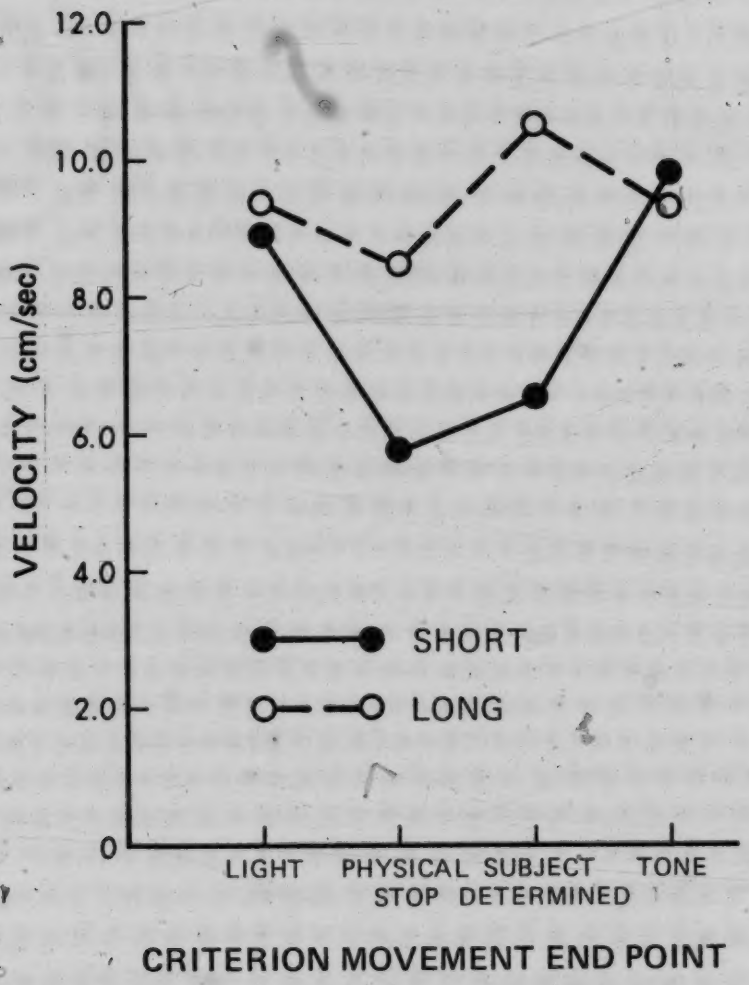


Figure 14. The interaction between movement distance and end-point for average velocity.

non-significant ($p>.05$).

Previous studies (Marteniuk, Shields & Campbell, 1972; Experiment 6) have shown that movement velocity has little influence on movement accuracy and precision. The present analysis revealed similar results. The correlations between average velocity and CE for the short and long distance conditions were +0.32 and +0.60, respectively. Over response strategy conditions the correlation between average velocity and CE ranged from +0.45 to +0.49. The correlations for the end-point conditions were +0.67 for tone, +0.66 for light, +0.29 for the physical stop and +0.22 for the subject determined stop. Substantially lower correlations were found between average velocity and AE. The correlation for the short distance was +0.08 and the correlation for the long distance was +0.60. The correlations over the three response strategies for average velocity and AE were only +0.38 for the *less than* condition, +0.21 for the *equal to* condition and +0.38 for the *greater than* condition. Over the four end-point conditions the correlations ranged from +0.18 to +0.59. When the relationships between average velocity and either VE or AV are examined, the size of the correlation coefficients continue to decrease, not exceeding +0.25 for any of the conditions, of movement distance, response strategy or end-point. For all four error scores the most prominent trend was for average velocity and reproduction performance to be most highly correlated over the end-points of light and tone. Low positive and negative correlations were found for the physical stop and subject determined stop end-points.

The correlations between the criterion and reproduction distances for average velocity were reported to be very high in Experiments 6 and 7. Similar high correlations were found in the present experiment. As

shown in Table 3, these correlations were lowest for physical stop and highest for subject determined stop. The correlations were also higher for the short distance than the long distance. Over the response strategy conditions the correlations between the criterion and reproduction distances ranged from +0.86 to +0.91.

The positive (A), constant (B) and negative (C) velocity phases of the criterion and reproduction movements were experimenter-defined in Experiment 6 and Experiment 7. These three velocity phases were more accurately determined in the present experiment. The average velocity curves of the short and long criterion distances for the various end-points are shown in Figures 15 and 16, respectively. There was no significant difference between the tone and light end-point conditions and a single average velocity curve represents the two conditions ($p>.05$). The average velocity curves of the short reproduction distance for the different end-points is depicted in Figure 17, and the corresponding velocity curves of the long reproduction distance in Figure 18. As in the case of the criteiron distances, the light and tone end-points were not significantly different ($p>.05$) and are plotted as one velocity curve. The primary difference between the criterion and reproduction curves was that for the light, tone and physical stop criterion distance end-points there was no negative velocity phase as demonstrated for reproduction. This was due to the instantaneous loss of velocity registered by the computer when these criterion end-points were reached.

A comparison of the acceleration and deceleration phases over all treatment conditions produced a high correlation (+0.86). The correlation between the acceleration and constant velocity phases was +0.54, while

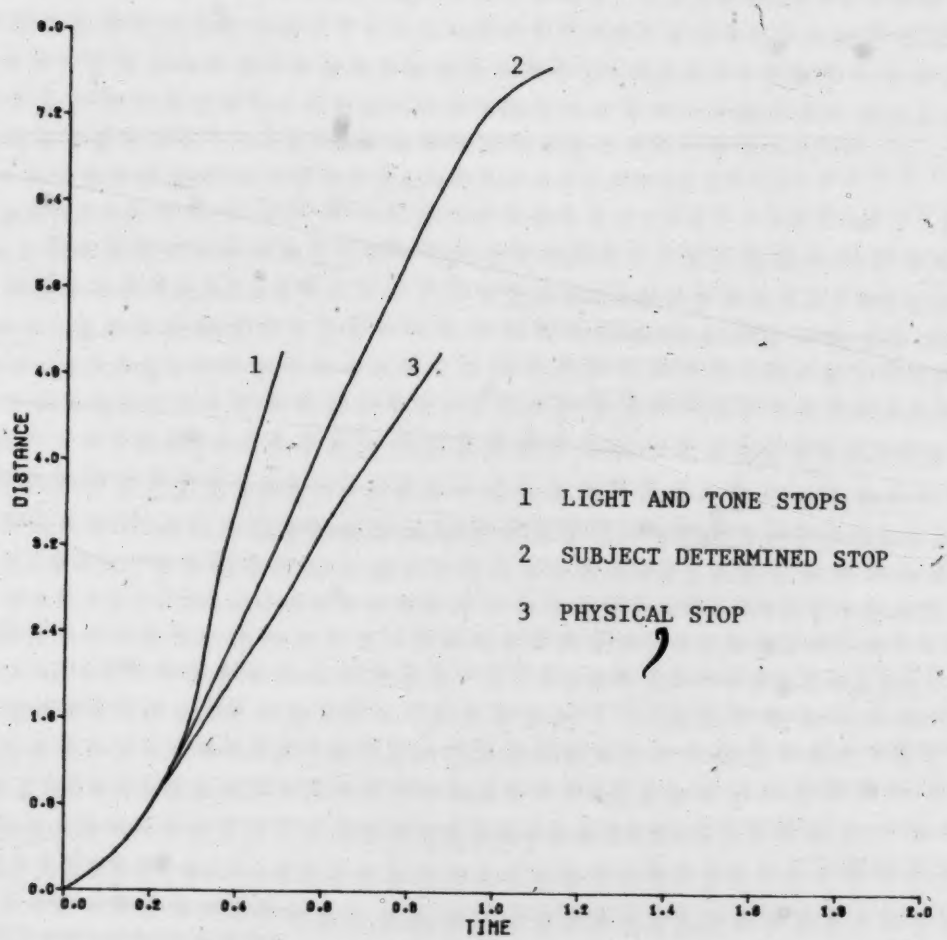


Figure 15. Average velocity curves of the criterion short distance for the four end-points.

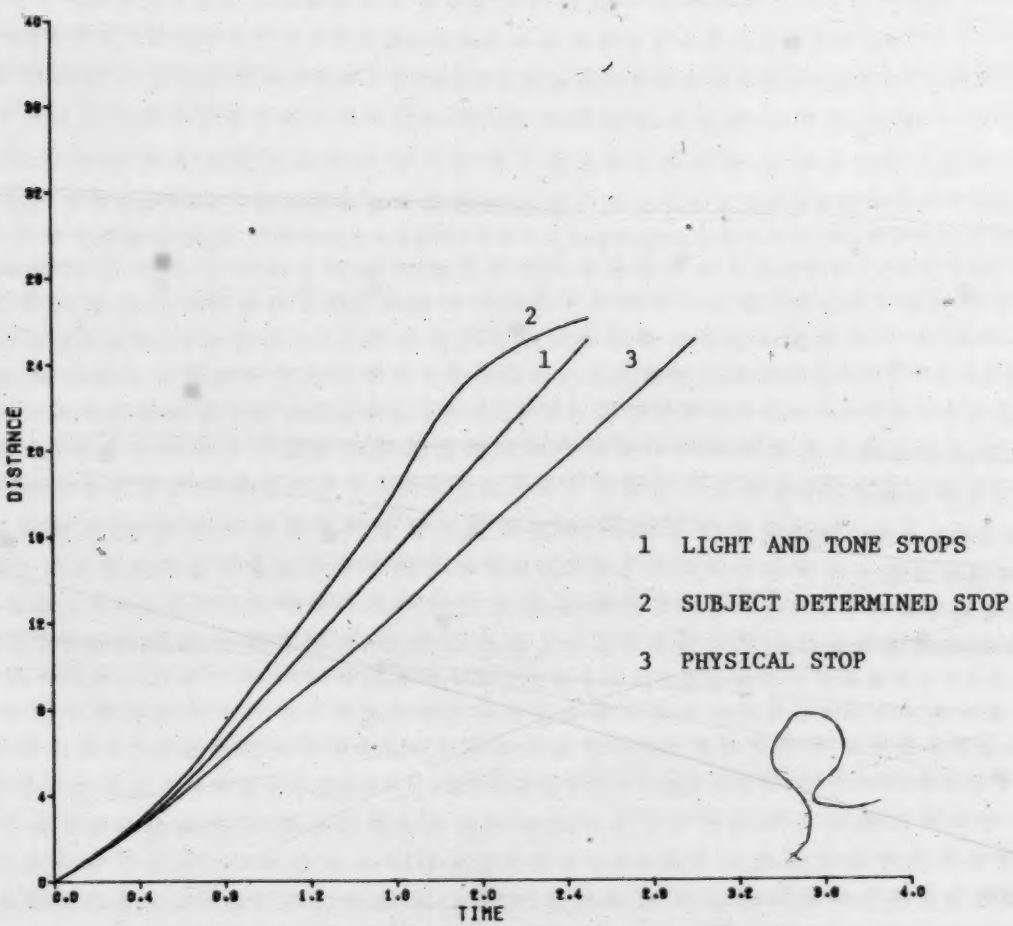


Figure 16. Average velocity curves of the criterion long distance for the four end-points.

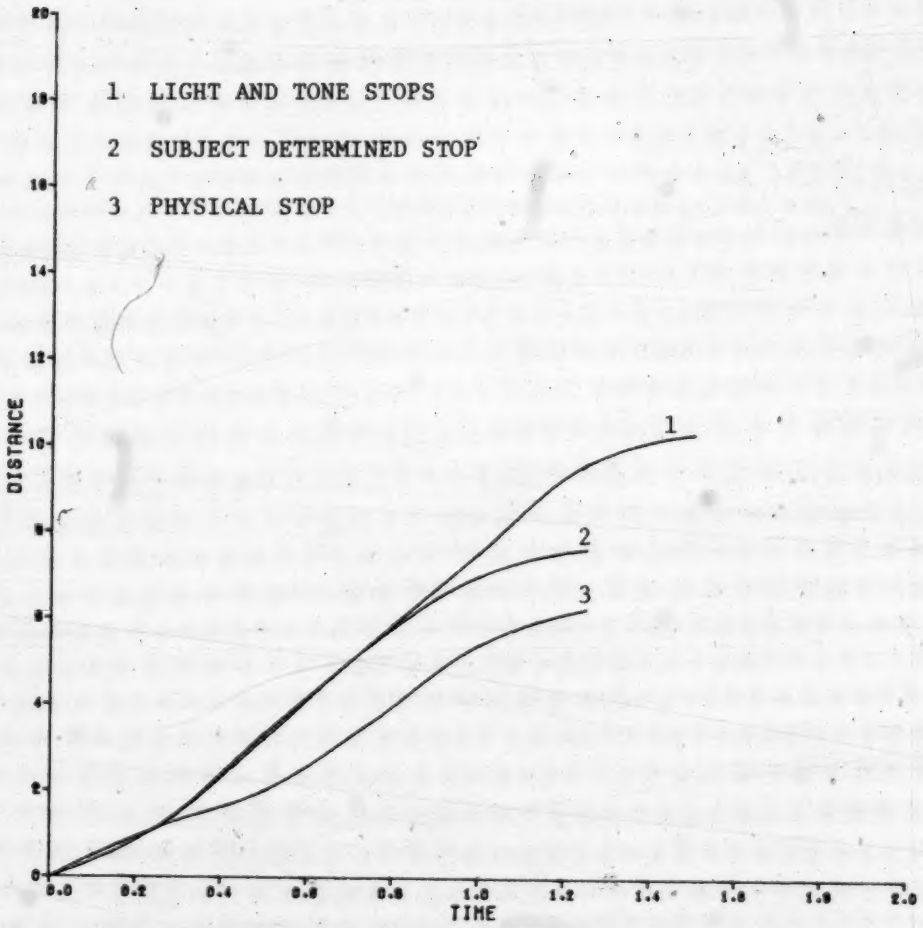


Figure 17. Average velocity curves of the short reproduction movements for the four end-points.

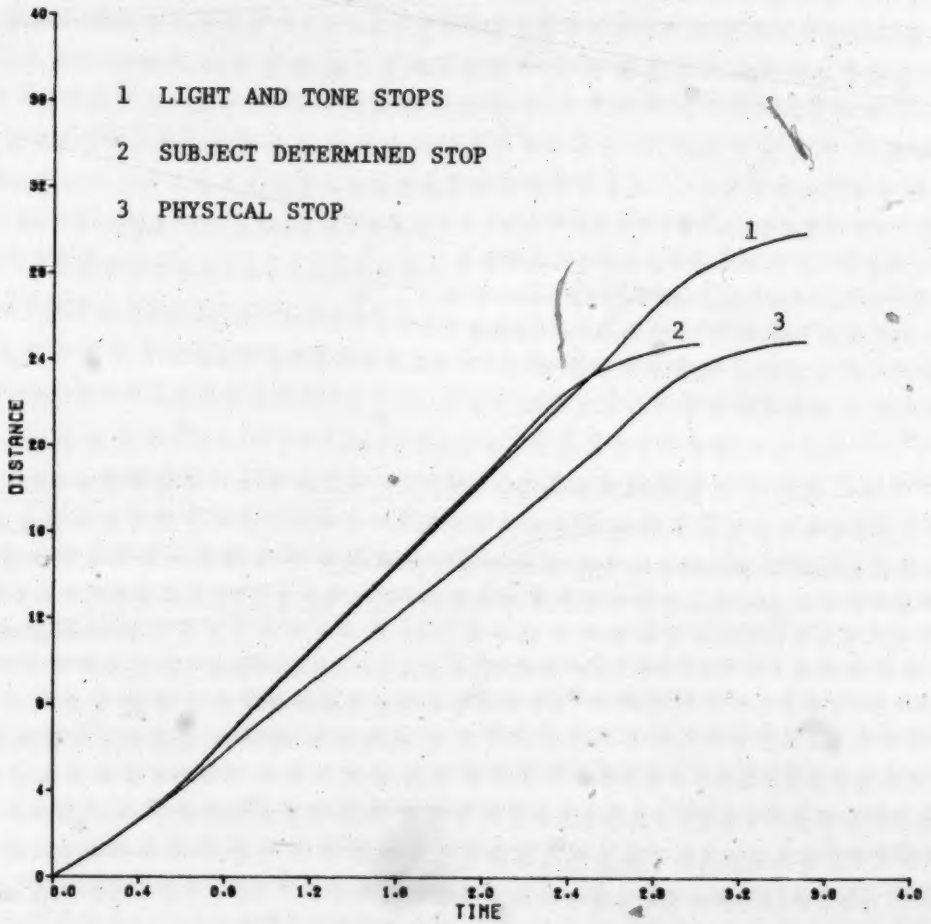


Figure 18. Average velocity curves of the long reproduction movements for the four end-points.

TABLE 3

The Correlations Between the Criterion and Reproduction Distances for Movement Distance and End-point

Movement Distance	End-point				
	Tone	Light	Physical Stop	Subject Determined	
Short	0.91	0.94	0.90	0.95	
Long	0.90	0.91	0.80	0.92	

All correlations were positive

the correlation was even lower between the deceleration and constant velocity phases (+0.45). There was no trend for higher correlations between the three velocity phases to be associated with the *greater than* strategy as reported in Experiment 7. The adjustments in movement distance over the three response strategies were produced in the constant velocity phase of the movement for both short and long distances. Movement distance, however, was a factor in the correlations between the various velocity phases of the reproduction movements. Correlations over the response strategies for the three velocity phases were somewhat higher for the short distance (+0.63 to +0.91) than for the long distance (+0.41 to +0.78).

Discussion

Wilberg and Tannis (1974) reported that the type of criterion movement end-point utilized in a distance reproduction experiment affects the accuracy of the reproduction performance, especially for distances exceeding 10 cm. They found that performance most accurate with the physical stop, while the sound end-points were associated with an overshooting tendency and the subject determined stop with an undershooting tendency. Criterion movement end-point was also found to influence reproduction accuracy in the present experiment and this effect was most significant for the long (25.0 cm) distance. Reproduction performance was most accurate for the subject determined stop and physical stop and least accurate for light and tone, generally supporting the findings of Wilberg and Tannis (1974). There was, in addition, an overshooting tendency associated with the light and tone end-points. This tendency was probably the result of subjects' attention being biased to the light and tone signals in deterrance to the production of the criterion movements. Such an attentional bias would be analogous to the conditions producing prior entry in temporal order judgements (Sternberg, Knoll & Gates, 1971; Frey, 1975) and cause a positive CE-shift in the judgements of criterion movement end-points. In essence, due to the attentional bias subjects would perceive the criterion distances to be longer than the actual defined lengths (5.0 and 25.0 cm). Reproduction performance, therefore, would demonstrate an overshooting tendency in relationship to the defined criterion distances, but this tendency would be an artifact of the experimental task. Functionally, end-point should not influence reproduction per-

formance and there was no affect of end-point in this experiment on the precision (as measured by VE and AV) with which reproductions were produced.

Wilberg and Tannis (1974) argue that criterion movements actively generated and defined by the subject seem to accentuate the range effect as compared to movements that are experimenter-defined, but the present results indicate no such trends. The performance patterns associated with the range effect were equally evident in both criterion movements made to a physical stop or a subject determined stop.

While end-point does not appear to be an important factor in reproduction performance, response strategy can modify performance to a considerable degree. Previous research (Buckolz, 1974; Experiments 5 and 7) has shown that response strategy formation can supercede the central tendencies usually demonstrated in distance recall data. Subjects can be over-estimators or under-estimators and the present results support this conclusion. Also replicated in the present experiment were the prevalent findings that short distances are more accurately and precisely reproduced than long distances (Laabs, 1973; Experiment 2) and range effect tendencies are generated with the accurate reproduction of a range of distances (Pepper & Herman, 1970; Experiments 2 and 4). These are general characteristics of distance reproduction, however, and may not be reliable in the prediction of individual performance.

The results for average velocity, similar to those for the error scores, generally supported preceding research (Marteniuk, Shields,& Campbell, 1972; Experiments 6 and 7). The criterion and reproduction movements were produced at similar average velocities when the criterion movement was made to a physical stop or subject determined stop. Also

no significant changes occurred in average velocity over the three response strategies. Disparities in average velocity that were demonstrated between the movement set and movement distance conditions appeared to be related to the light and tone end-points. Regardless, however, of the end-point, response strategy or movement distance examined, velocity of movement correlated poorly with the accuracy and precision of the distance reproduced. This indicates that movement velocity has little influence on movement accuracy and precision.

Several of the prior experiments in this series have been concerned with how movement reproductions are adjusted to produce range effect and response strategy performance patterns (Experiments 6 and 7). Such an approach involves dividing the criterion and reproduction movements into acceleration (A), constant velocity (B) and deceleration (C) phases. These three phases, however, are not always present in approach movements. Experimenter defined movements to physical or signal (light and tone) end-points do not have a deceleration phase since there is instantaneous velocity loss at the termination of the movement. Several of the criterion movements employed in the present experiment had this characteristic. In movements made to a target the period of constant velocity is not usually demonstrated (Taylor, 1947; Vince, 1948). Also the relative sizes of the acceleration and deceleration phases depend on terminal accuracy (Annett, Gobly & Kay, 1958). The greater the accuracy of the movement the longer the deceleration phase. The velocity curves produced in the present study and those reported in Experiment 6 and 7 were characterized by a long constant velocity phase, with the acceleration and deceleration phases being short and of similar durations. The type of response strategy employed

probably best accounts for the constant velocity phase in criterion and reproduction movements and the elimination of this phase in movements made to a target. Kantowitz (1974) suggests that reproduction tasks favour a strategy of moving at a constant velocity. Both previous research (Marteniuk, Shields & Campbell, 1972) and the present study sustain this contention. Employing this strategy, adjustments in the movements would simply entail alterations in the length of the constant velocity phase (Experiments 6 and 7). This would definately be the most appropriate strategy for criterion movements made to an experimenter-defined stop because a period of deceleration is absent in these movements. Moreover, to intensify this strategy the acceleration and deceleration phases would be abbreviated, as shown in the present experiment. In contrast, the optimal response strategy for movements made to a target seems to be a fast acceleration phase followed by a slow terminal phase in order that maximal accuracy is realized (Annett, Galby & Kay, 1958; Beggs & Howarth, 1972).

It was proposed in the two foregoing studies (Experiments 6 and 7) that the constant velocity phase of a short movement and a combination of both the constant velocity and deceleration phases of a long movement are adjusted to produce range effect and response strategy performance patterns in distance reproductions. This conclusion can now be modified based on the current findings. Only the constant velocity phase is lengthened or shortened in both short and long movements. The interaction between the middle (B) and final (C) phases of the long reproduction movements found in Experiment 6 and Experiment 7 was likely due to the over-estimation of the deceleration phase. The last 1.0 sec of a long movement was defined as the deceleration

component of the movement in these experiments, but the present results indicate this phase is a considerable shorter proportion of the total reproduction time (Figure 18). Consequently, a portion of the constant velocity phase was confounded with the deceleration phase producing the spurious interaction. No such problem was evident in the examination of the short reproduction movement since the defined deceleration phase was 0.5 sec, a closer approximation to the actual duration of this phase.

Although the performance patterns associated with the bracketing response strategies are generated by changes in the constant velocity phase of both short and long movements, subjects do appear to handle response strategies differently for short and long distances. This conclusion is intimated by the different error score distributions of the short and long distances for the three response strategies in Experiment 5. It is further suggested in the present study by the higher correlations between the three movement velocity phases for the short distance than the long distance over the various response strategies. There is not at the present time, however, a satisfactory explanation for why subjects should demonstrate this tendency to handle response strategies differently for different movement lengths.

Experiment 9

Recognition of Short and Long Distances

The recognition of stimulus events involving verbal materials has been a popular subject of investigation, however there has been little consideration given to the recognition of movement information. Marshall (1972) reported detrimental effects of delay on the recognition of kinesthetic information, but Kantowitz (1974) failed to support this conclusion. The different procedures employed in the two studies may possibly account for the conflicting findings. Marshall used a two-interval forced-choice recognition paradigm while Kantowitz employed same-different judgements. Kantowitz (1974) also demonstrated that for kinesthetic information recognition accuracy increased with the amplitude of the movement. Furthermore, performance varied with the type of recognition judgement made by the subject (same or different). When the distance to be recognized was longer than the criterion distance subjects were better able to discriminate the difference than when the distance to be recognized was shorter than the criterion.

The present article extends the examination of recognition for movement information with both short (5.0 cm) and long (25.0 cm) distances being tested. The reproduction of short and long distances has been examined extensively (Pepper & Herman, 1970; Laabs, 1973; Wilberg & Hall, 1976) but previous recognition studies (Marshall, 1972; Kantowitz, 1974) have considered only long distances (movement lengths exceeding 13.0 cm). The present experiment also investigated the occurance of any central tendencies in distance recognition judgements which were not reported by Marshall (1972) and Kantowitz (1974) but have usually been demonstrated in distance reproduction studies (Pepper & Herman, 1970; Laabs, 1973; Wilberg & Hall, 1976).

Method

Subjects

The subjects were six students from the University of Alberta. Each subject received $2.00 per hour for participating in the experiment. The only participation requirement was that subjects wrote with their right hand.

Apparatus and Task

A meter bar (uncalibrated) mounted on a dexion frame served as a track along which the subjects produced linear movement distances by moving a plastic cursor with a metal handle. The cursor was attached to a 10-turn potentiometer from which the output, after passing through a voltage divider/amplifier box, was connected to a digital multimeter (Fluke 8000A). When the cursor was moved, the distance traversed was recorded in mv on the digital multimeter. The digitized voltage was then converted to its movement distance equivalent in mm.

The subject sat comfortably in front of the apparatus wearing a blindfold and moved the cursor horizontally from the left to right with the right hand. The range employed on the meter bar was a maximum of 65.0 cm, all distances being made within that range. The experimenter set the length of the distances with an adjustable stop that was mounted adjacent to the track.

Design

There were two criterion distances, short (5.0 cm) and long (25.0 cm). The subjects were given 40 trials presented in random order with 20 trials for each of the two criterion distances.

Procedure

A criterion distance and then a second distance (termed the recognition distance), which the subject judged as being *less than, equal to,* or *greater than* the criterion distance were presented on a trial. The distances were presented by having the subject grasp the cursor and move it until contacting the physical stop. The criterion distance and recognition distances had different start-point locations so subjects could not utilize location information in making their judgements. Six different start-points were used in the experiment. For all trials, the criterion and recognition distances were of equal length but the subjects were uninformed of this situation. However, it was stressed that the occurances of the three possible relationships between the criterion and recognition distances were not equally probable in order to reduce any response biasing effects (Parducci, 1975). Prior to the actual testing session each subject received a practice session consisting of 60 trials. The practice session was given so that subjects would become familiar with the movement range and therefore more clearly demonstrate any central tendencies in their recognition judgements during the experimental testing.

Results

The probability of judging the recognition distance as *less than* *equal to* or *greater than* the criterion distance for the short (5.0 cm) length over trials is depicted in Figure 19. Over 20 trials the probability of making a correct response (judging the criterion and recognition distances as equal) was only 0.54. When making incorrect judgements subjects moved from a *greater than* to a *less than* judgement set over the forty trials. This trend corresponds to that associated with the range effect. During the testing, as subjects develop an overshooting tendency the recognition distance would have to be extended in order to maintain the relationship between the judgement probabilities established during the initial test trials. Since in the present experiment the criterion and recognition distances were always equal, the predicted trend would be for an increase in *less than* judgements over trials, as demonstrated.

In Figure 20 the recognition judgement probabilities over trials for the long (25.0 cm) criterion length are shown. The probability of making a correct judgement (0.31) is substantially less for the long distance than the short distance. The higher probability for judging the recognition distance to be *greater than* the criterion distance corresponds to the central tendency of the range effect for long distances. This tendency is apparent from the onset of the test session not developing over trials as evidenced for the *less than* judgement tendency associated with the short distance.

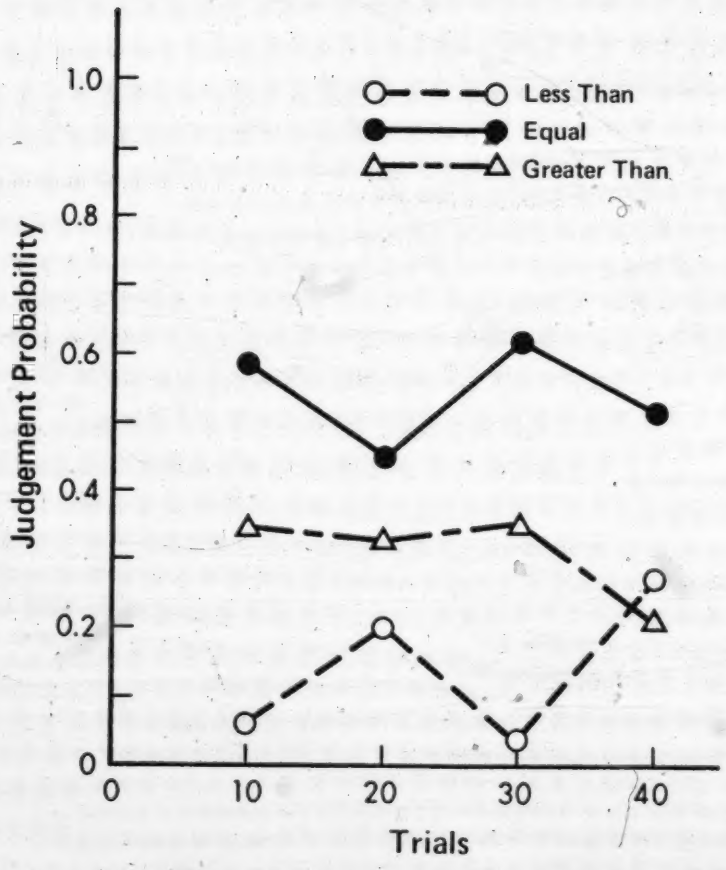


Figure 19. Recognition judgement probabilities for the short distance (5.0 cm) as a function of trials.

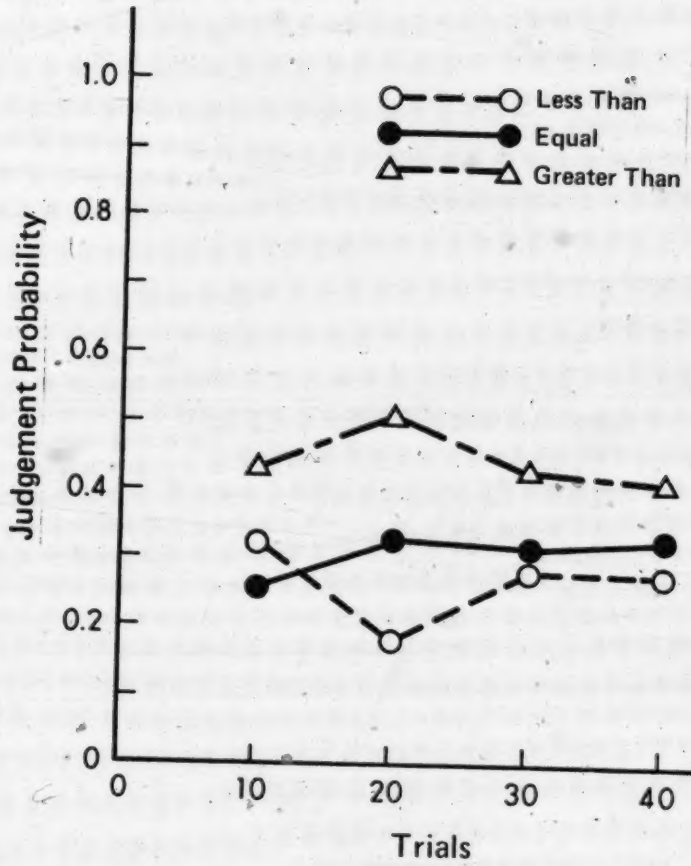


Figure 20. Recognition judgement probabilities for the long distance (25.0 cm) as a function of trials.

Discussion

In addition to the present results, the results of research by Marshall (1972) and Kantowitz (1974) involving different procedures support the conclusion that movement distance can be accurately recognized. One substantial difference in the present study was that the accuracy of performance was considerably lower than in previous studies. The probability of a correct judgement did not exceed .60 in this experiment while both Marshall (1972) and Kantowitz (1974) report values over .70. A possible reason for this difference is that having to make a directional decision (less than - greater than) in addition to a same-different decision reduces performance accuracy. The basis of this arguement comes from the research of Blick (1969) in which subjects were required to recognize various lengths that were visually presented. Subjects made same-different judgements in the first part of the experiment and both same-difference and longer-shorter judgements in the second part of the experiment. She found that adding a longer-shorter decision to the same-different decision already required depressed the accuracy of the latter. Since success in the same-different decision did not adequately predict success in the longer-shorter decision, it was postulated that the decision process takes up space in short-term memory so that accuracy is decreased by additions to the decision process.

Recognition performance was substantially less for the long distance than the short distance in the present study. Kantowitz (1974) employing Fitts' ID in a same-different recognition paradigm reported an increase in recognition accuracy for greater movement lengths. The different findings demonstrated in the two studies may be the result of the different responses required, the separate performance measures

employed or because the shortest amplitude in the Kantowitz study was 16.0 cm compared to the 5.0 cm distance used in this experiment.

The central tendencies associated with the range effect are generally demonstrated in movement reproduction studies. For short distances Pepper and Herman (1970) term such tendencies an overshooting set while for long distances an undershooting set is demonstrated. The results of the previous experiments in this series indicate that the range effects are related to the comparator stage for the criterion and reproduction movements. Since comparisons between criterion and recognition distances are required in the present experiment, it is reasonable to assume that tendencies similar to those associated with the range effect may be demonstrated. The present results do show this type of performance pattern developing over trials. There was a high probability of judging the recognition distance to be greater than the criterion for the long movement condition. This bias in judgement would be evidenced if an undershooting set developed since the criterion and recognition movements were of equal length. To evoke an *equal to* or *less than* response in this situation the recognition distance would had to have been shortened, thereby corresponding to the undershooting tendency shown for long distances in reproduction experiments. A complimentary pattern of results was evidenced for the short criterion distance. When making incorrect judgements subjects moved from a *greater than* to a *less than* judgement set over trials. This trend, however, is slow to develop and may be the result of the higher recognition performance for the short criterion distance as compared to the long criterion distance.

Experiment 10

Modified Movement Recognition

The majority of short-term motor memory studies have employed movement reproduction rather than movement recognition to examine various characteristics of motor memory. Recently, however, several researchers have utilized recognition paradigms to circumvent several of the problems associated with the typical reproduction task (Marshall, 1972; Kantowitz, 1974). These problems include difficulties in the production of accurate movements (Fitts, 1954), differences in criterion (experimenter defined) and reproduction (subject defined) movements which make it difficult to ascertain what is being tested for retention (Bahrick, Fitts & Schneider, 1955), and uncertainty concerning which error score (CE, VE, AE) is the most appropriate for measuring reproduction performance. The use of movement recognition paradigms, however, also poses some inherent difficulties. One such difficulty is that different recognition tasks can produce conflicting results. Marshall (1972) using a two-interval forced-choice recognition paradigm found detrimental effects of retention interval (unfilled) on distance recognition performance. Kantowitz (1974) failed to find any decrement in distance recognition performance over either a filled (interpolated tapping task) or unfilled retention interval employing the more conventional same-different judgements.

Since both movement reproduction and recognition present some innate problems when employed in short-term motor memory experiments, it might be beneficial to utilize both techniques in the same experiment. Lockhart, Craik and Jacoby (1975) suggest that examining the consequences of recognition for subsequent retrieval may be a worth-

while approach to analysing recognition itself. The present experiment examines this suggestion using a procedure that is referred to as modified movement recognition. This procedure first involves the subject judging the relationship between a criterion movement and a recognition (test) movement similar to the procedure utilized in the previous experiment. If the subject judges the recognition movement to be different from the criterion movement the subject modifies or adjusts the recognition movement in an attempt to make it equal to the criterion.

Method

Subjects

The six subjects from the ninth experiment again participated receiving $2.00 per hour.

Apparatus and Task

The apparatus and task employed in Experiment 9 were used in this experiment.

Design

Two criterion distances, a short (5.0 cm) and a long (25.0 cm), were presented to the subjects. Each subject was given 20 trials for each of the two criterion distances and these trials were randomized.

Procedure

The procedure was essentially the same as that employed in Experiment 9 with the addition of a possible movement adjustment in the recognition distance following the recognition judgement. If the criterion and recognition distances were judged to be different, the subject endeavored to make an equalizing movement adjustment for the recognition distance. In order to allow the subject to make any alteration in the length of the recognition distance, the end-point stop was removed at the completion of the recognition move. Thus, free movement of the cursor in either a left or right direction at this stage of a trial was possible. As in the previous experiment the subjects were instructed that any of the three possible relationships (less than, equal to, or greater than) between the criterion and

recognition distances could occur on a given trial. It was stressed that the occurrance of the three relationships were not equally likely. Unknown to the subjects, the two distances were always equal in length.

Data Analysis

Absolute error (AE) and signed constant error (CE) were calculated for the movement adjustments.

Results

The probability of judging the recognition distance as *less than, equal to* or *greater than* the criterion distance for the short movement length (5.0 cm) is shown in Figure 21. The probability of making a correct response was 0.45. The probability of making a *greater than* response was 0.24 and the probability for making a *less than* response was 0.31. For the long movement length (25.0 cm) the probability of a correct response was 0.28. The probability of giving a *greater than* response was 0.48 and the probability responding *less than* was 0.24. The three types of responses plotted over trials are shown in Figure 22.

An analysis of variance performed on the movement adjustment data showed a significant difference between the adjustements made for the short and long distances. As indicated by absolute error, the magnitude of the preceived error (the difference between the criterion and recognition lengths) was larger for the long distance (19.4 mm) than the short distance (7.5 mm), $F(1,194) = 13.91$, $p<.01$. Algebraic error corresponded with the tendencies of the range effect, $F(1,194) = 5.38$, $p<.05$. Generally subjects tended to increase the recognition movement for the short distance (2.0 mm) and decrease it for the long distance (-7.1 mm) after making a difference judgement.

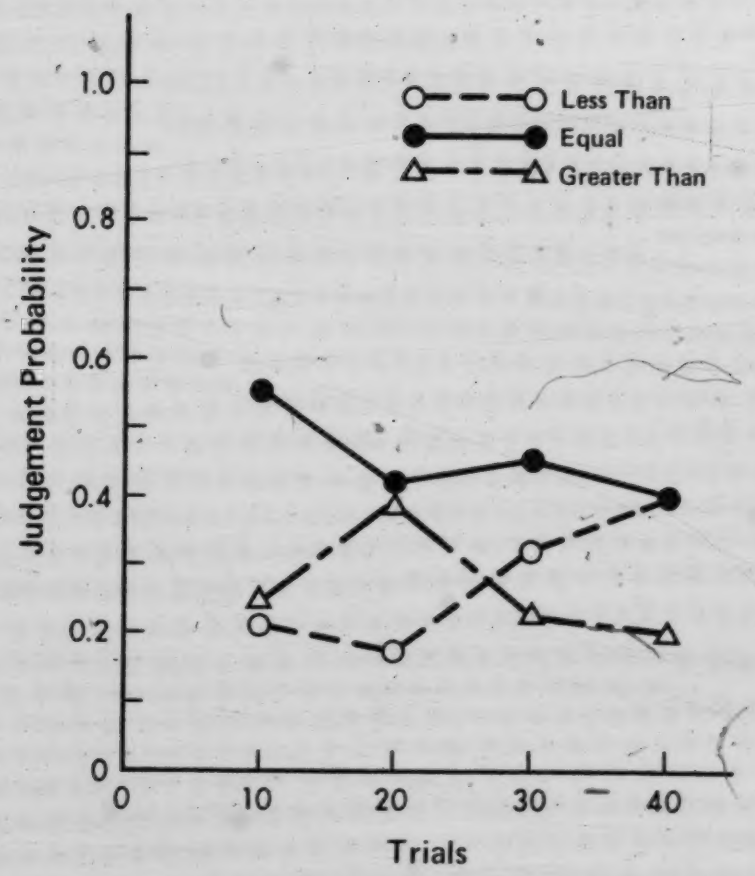


Figure 21. Recognition judgement probabilities for the short distance (5.0 cm) as a function of trials.

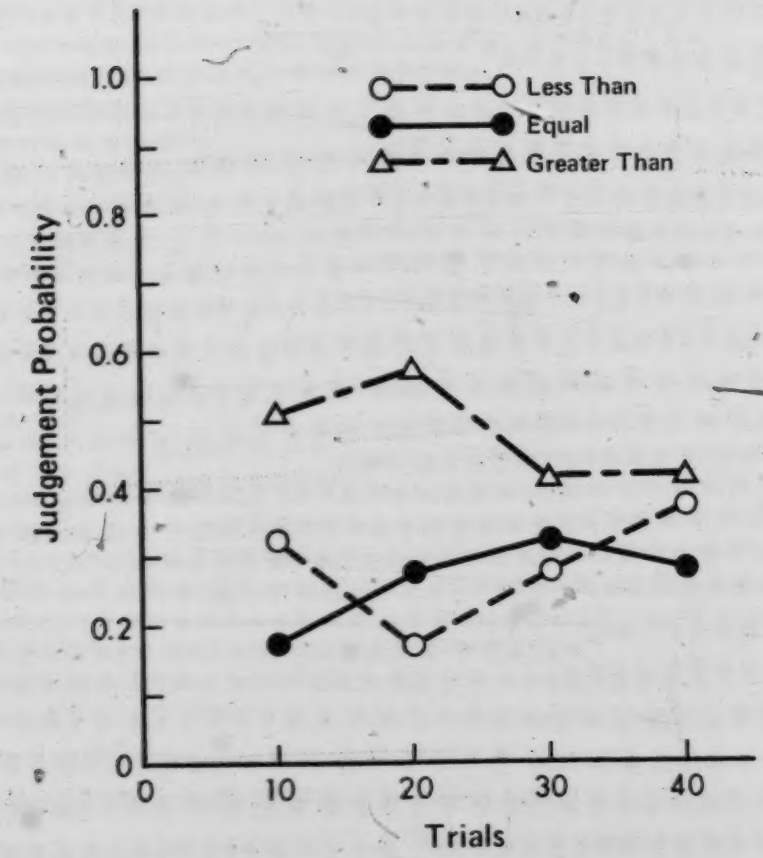


Figure 22. Recognition judgement probabilities for the long distance (25.0 cm) as a function of trials.

Discussion

Modified movement recognition reduces the probability of a correct recognition (judging the criterion and recognition distances to be equal). The probability of judging the criterion and recognition distances as equal for the short criterion distance was 0.45 in this experiment compared to 0.54 in Experiment 9. The probability of a correct judgement for the long criterion movement distance was 0.31 in Experiment 9 but only 0.28 in the present experiment. The research of Blick (1969) on the recognition of visually presented lengths predicts such trends in recognition performance. She proposes that the addition of decisions to be made in a recognition task concerning the relationship between the criterion and recognition items depresses performance by taking up space in short-term memory. The addition of adjusting the recognition movement to equal the criterion movement in the present experiment would certainly involve such an additional decision over the basic recognition judgement; namely, determining the size of the adjustment.

The probability of giving a *greater than* response in the long criterion distance conditions and a *less than* response in the short criterion distance conditions was also accentuated with the modified movement recognition technique over those results found in Experiment 9. The effect was most significant for the short criterion distance condition in that after 40 trials the probability of a *less than* response was equal to that of making a correct judgement. The movement adjustment data also reflect this trend. The adjustments for the short distance (2.0 mm) were a much larger proportion of the criterion

distance than the adjustments for the long distance (-7.1 mm).[1] If the comparator stage for the criterion and test distances is responsible for the development of response biasing tendencies in reproduction and recognition experiments as postulated in Experiments 2, 3 and 9, then the findings of the present Experiment indicate that required adjustments to recognition distances will act to modify this stage and accentuate any such response tendencies.

Experiment 11

Response Strategy and Distance Recognition

Bracketing response strategies have been employed by Buckolz (1974) and in several experiments (1,5,7 and 8) of the present research in the examination of movement reproduction. It was demonstrated that subjects can form strategies producing response biases which may approximate the central tendencies of the range effect, but not be related to the stimulus range. Subjects have also been required to make bracketing type responses in recognition studies. Blick (1969) had subjects make both same-different judgements and longer-shorter judgements in the recognition of various visually presented lengths. Adding a longer-shorter decision to a same-different decision already required decreased recognition performance. Subjects judgements when required to make both directional and same-different decisions also show certain response tendencies, as demonstrated in the previous two experiments. There is a higher probability of giving a *less than* judgement than a *greater than* judgement for a short criterion distance when a judgement of *equal to* is correct. The reverse is the case for long distances in a movement range. There is a greater probability of giving a *greater than* than a *less than* judgement when a judgement of *equal to* is correct. It was postulated in the present experiment that manipulating the recognition distances according to bracketing type response strategies might also be useful in the examination of recognition performance for movement distance. Therefore, in this experiment the recognition (test) distance on a given trial was physically less than, equal to, or greater than the criterion distance and subjects had to judge which of the three possible relationships occurred.

Method

Subjects

The subjects were six students from the University of Alberta. Each subject received $2.00 per hour for participating in the experiment. The only participation requirement was that subjects wrote with their right hand.

Apparatus and Task

The apparatus and task were identical to those employed in Experiments 9 and 10.

Design

Two criterion distances were utilized, 5.0 cm and 25.0 cm. Three recognition distances for each of the two criterion distances were labelled as follows: for the short (5.0 cm) criterion distance the recognition distance was *less than* (3.0 cm), *equal to* (5.0 cm), or *greater than* (7.0 cm) this distance; for the long (25.0 cm) criterion distance the recognition distance was *less than* (20.0 cm), *equal to* (25.0 cm), or *greater than* (30.0 cm) this distance. Each subject received 7 trials for each of the six different conditions and the 42 total trials were randomly ordered.

Procedure

The procedure was similar to that employed in Experiment 9. A criterion distance and then a second distance (termed the recognition distance), which the subject judged as being *less than*, *equal to* *greater than* the criterion distance, were presented on a given trial.

The criterion and recognition distances had different start-point locations so subjects could not use location information in making their judgements. Six different start-points were used in the experiment. On a given trial the recognition distance could be *less than*, *equal to* or *greater than* the criterion distance. Although there were an equal number of the three types of recognition distances the subjects were told that the occurrences of the three possible relationships between the criterion and recognition distances were not equally probable. This was done to eliminate any response biasing effects (Parducci, 1975).

Results

The recognition judgement probabilities for the short (5.0 cm) distance are shown in Figure 23. The probability of a correct recognition is considerably higher in this experiment than in Experiment 9. The probability of making accurate judgements on the *less than* and *greater than* trials were 0.78 and 0.73, respectively. The probability of making a correct response when the criterion and recognition distances were of equal length was 0.74. Moreover, the response tendency associated with the short distance of giving *less than* judgements when incorrectly judging criterion and recognition distances of equal length virtually disappeared with the incorporation of the three movement distances.

An examination of Figure 24 indicates that for the long (25.0 cm) distance subjects continued to have difficulty correctly judging the criterion and recognition distances to be equal even though *less than* and *greater than* recognition distances were presented. The probability

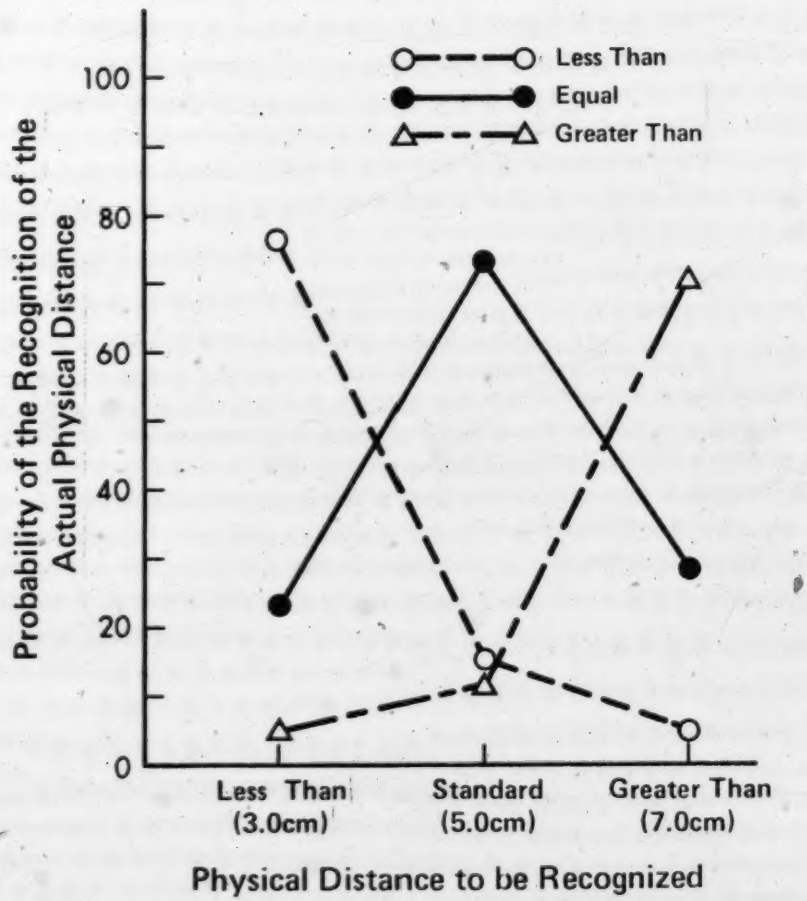


Figure 23. Recognition judgement probabilities for the physically less than (3.0 cm), equal to (5.0 cm) and greater than (7.0 cm) movement lengths for the short distance.

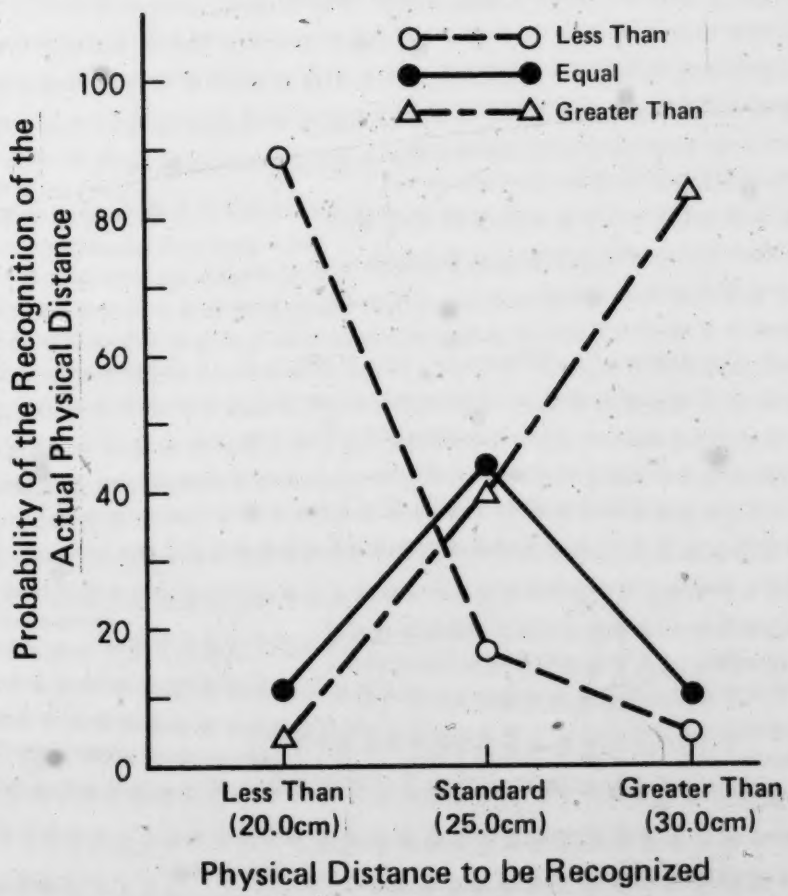


Figure 24. Recognition judgement probabilities for the physically less than (20.0 cm), equal to (25.0 cm) and greater than (30.0 cm) movement lengths for the long distance.

of making accurate judgements on the *less than* and *greater than* trials were 0.88 and 0.83, respectively. The probability of making a correct response when the criterion and recognition distances were the same length was only 0.43. Furthermore, the frequency with which the recognition distance was judged to be greater than the criterion distance on these trials demonstrated the continued presence of this previously reported response tendency (Experiments 9 and 10).

Discussion

The probability of a correct recognition for the short distance is considerably higher in this experiment than in Experiment 9. The definite increase in the probability of correctly recognizing the criterion and recognition distances as being equal would seem to be a consequence of including the other two recognition distances. Probably subjects were better able to formulate what constituted a move *less than* or *greater than* the criterion and thus more accurately judge the different relationships. The reduction in the response tendency to give *less than* judgements for incorrect decisions in the *equal to* condition for the short distance supports this assumption. The same effect was demonstrated to a lesser degree for the long distance. Subjects continued to have some difficulty correctly judging the criterion and recognition distances to be equal in this condition.

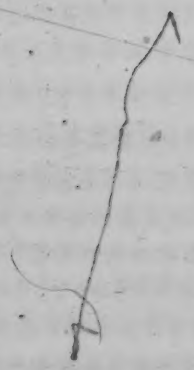
The improvement in recognition performance with the inclusion of three recognition distances corresponding to the three types of recognition judgements has several possible explanations. Some studies have demonstrated what appears to be positive effects of organization on recognition (Jacoby, 1972; Mandler, 1972). Perhaps with the addition of the less than and greater than recognition distances subjects were better able to categorize or implement some other form of organization by which to judge the relationship of the criterion and recognition distances.

A second explanation comes from the levels of processing model proposed by Craik and Lockhart (1972). This model centers around a continuum of perceptual analyses. Stimuli are encoded and subject to

analysis at three different levels or domains; physical, phonemic and semantic. Further processing is also possible within a particular domain and this is termed elaboration (Lockhart, Craik & Jacoby, 1976). A level of processing interpretation of the present data would assume that the increase in recognition performance was a function of elaboration within a domain. Elaboration enables the preceiver to distinguish the target event from other similar events. Therefore, increasing the number of recognition distances would permit further analysis of the stimulus items at the same processing level and provide for a more accurate relationship judgement of the criterion and recognition distances.

Recognition performance was significantly lowet in the *equal to* condition for the long distance in this study. Kantowitz (1974) found an increase in recognition accuracy for longer movement lengths. These conflicting findings are difficult to reconcile, especially in view of the very accurate recognition performances demonstrated in the *less than* and *greater than* conditions of the present study. The differences may be attributeable to the two types of paradigms and performance measures used in the two experiments. Kantowitz employed Fitts' ID in a same-different recognition task. Furthermore, in the Kantowitz experiment a more restricted range of rather long movements (16.0 - 25.0 cm) was utilized compared to the 5.0 and 25.0 cm distances of the present study.

Experiment 12



Distance Recognition, Response Strategy and Movement Adjustments

The examination of movement recognition has recently been undertaken by Marshall (1972) and Kantowitz (1974). Concern in these two studies focused on recognition performance for movement distance over filled (interpolated) and unfilled (rest) retention intervals. The recognition of movement distance has also been investigated in the present series of experiments with consideration being given to the influence of various types of response conditions on performance (Experiments 9, 10, 11). The response modes included combinations of both directional (longer-shorter) and same-different judgements, the use of multiple recognition (test) distances and a procedure termed modified movement recognition. This procedure first involves making a same-different decision and then an adjustment in the recognition distance to make it equal to the criterion distance if a difference decision is reached.

Modified movement reproduction was shown to reduce the probability of making a correct distance recognition in Experiment 10. The response biasing tendencies associated with the *equal to* condition were also accentuated with modified movement recognition. The reverse trends in recognition performance occurred with the incorporation of three recognition distances in Experiment 11, especially for the short-distance. The probability of a correct recognition increased while the response biasing tendencies diminished. The purpose of the present experiment was to examine how modified movement recognition and multiple recognition distances would interact to influence distance recognition performance when both were incorporated in the experimental paradigm.

Method

Subjects

The subjects were the same subjects that participated in Experiment 11.

Apparatus and Task

The apparatus and task used in the present experiment were identical to the apparatus and task used in experiments 9 through 11.

Design

The design was a 2 x 3 factorial with repeated measures on both factors. The first factor was movement distance consisting of two levels, short (5.0 cm) and long (25.0 cm). The second factor was recognition distance of which there was three levels: *less than* the criterion distance, *equal to* the criterion distance and *greater than* the criterion distance. Each treatment condition was replicated three times by every subject.

Procedure

A criterion distance and then a second distance (termed the recognition distance), which the subject judged as being *less than, equal to,* or *greater than* the criterion distance, were presented on a given trial. This was accomplished by the subject grasping the cursor and moving it until contacting a physical stop. The experimenter next repositioned the cursor to a new start-point location and the subject repeated the procedure. Six different start-point locations were

utilized to make location information irrelevant. On a given trial the recognition distance could be *less than*, *equal to*, or *greater than* the criterion distance. Three recognition distances for each of the two criterion lengths were labelled as follows. For the short (5.0 cm) criterion distance the *less than* recognition distance was 3.0 cm, the *equal to* recognition distance was 5.0 cm and the *greater than* recognition distance was 7.0 cm. For the long criterion distance (25.0 cm) the *less than* recognition distance was 20.0 cm, the *equal to* recognition distance was 25.0 and the *greater than* recognition distance was 30.0 cm. Although there were equal numbers of the three types of recognition distances it was stressed to the subjects that the occurrance of three possible relationships between the criterion and recognition distances were not equally probable. This was done to eliminate any response biasing effects (Parducci, 1965).

Data Analysis

Any movement adjustments made to the recognition distances were recorded in terms of algebraic error (CE) and absolute error (AE). If the criterion and recognition distances were not the same length and judged not to be equal by the subject, the difference between the movement adjustment (perceived error) and the actual difference was also calculated for both CE and AE.

Results

The probability of a correct response for the short criterion distance was 0.78 in the *less than* condition, 0.59 in the *equal to* condition and 0.70 in the *greater than* condition. As indicated in Figure 25, there was no significant tendency to give a *less than* response over a *greater than* response when an incorrect judgement was made in the *equal to* condition. The probability of a correct response for the long criterion distance was 0.91 for the *less than* condition, 0.49 in the *equal to* condition and 0.92 in the *greater than* condition. As with the short criterion distance, no significant response tendency was demonstrated for incorrect judgements in the *equal to* condition (Figure 26).

A 2 x 3 analysis of variance with repeated measures was performed on the movement adjustment data. There was no difference between the short (5.0 cm) and long (25.0 cm) distances for algebraic error ($p>.05$). However, absolute error was significant, $F(1,46) = 13.92$, $p<.01$, the short distance being altered by 1.3 cm while the long distance was altered by 3.4 cm. For both algebraic error [$F(2,58) = 9.36$, $p<.01$] and absolute error [$F(2,58) = 7.41$, $p<.01$] recognition distance was significant. When the recognition distance was less than the criterion distance subjects extended the length of the recognition distance (short = 1.3 cm and long = 4.2 cm). When the recognition distance was greater than the criterion distance subjects decreased the length of the recognition distance (short = -1.5 cm and long = -4.0 cm). There were no significant interactions ($p>.05$).

The differences between the adjustment movements and the actual physical differences for the three recognition distances were also

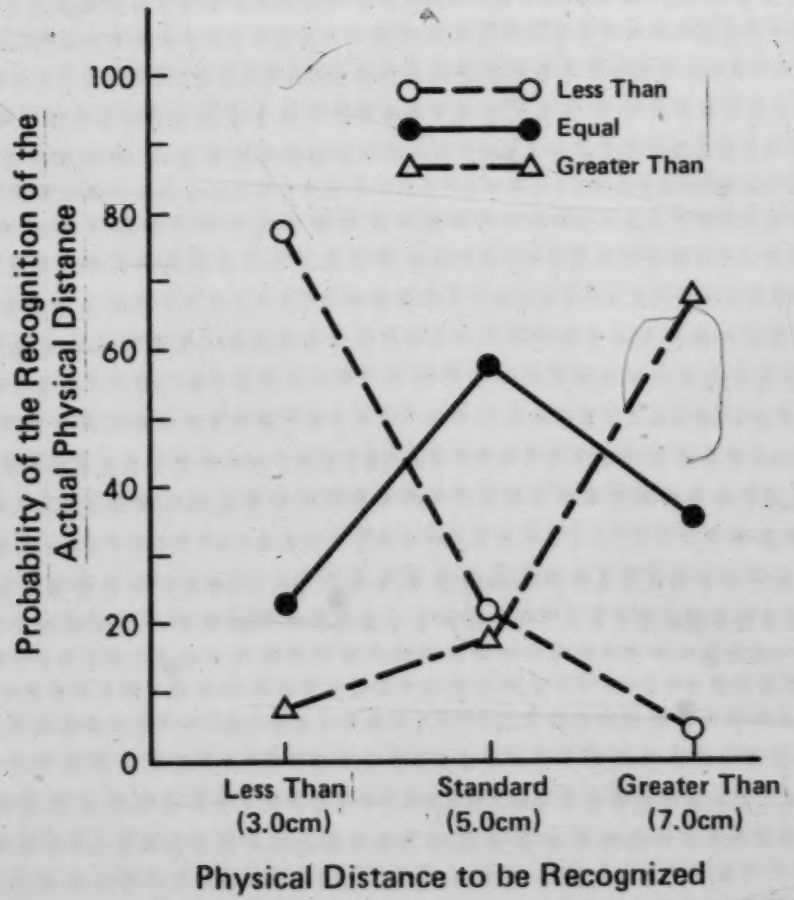


Figure 25. Recognition judgement probabilities for the physically less than (3.0 cm), equal to (5.0 cm) and greater than (7.0 cm) movement lengths for the short distance.

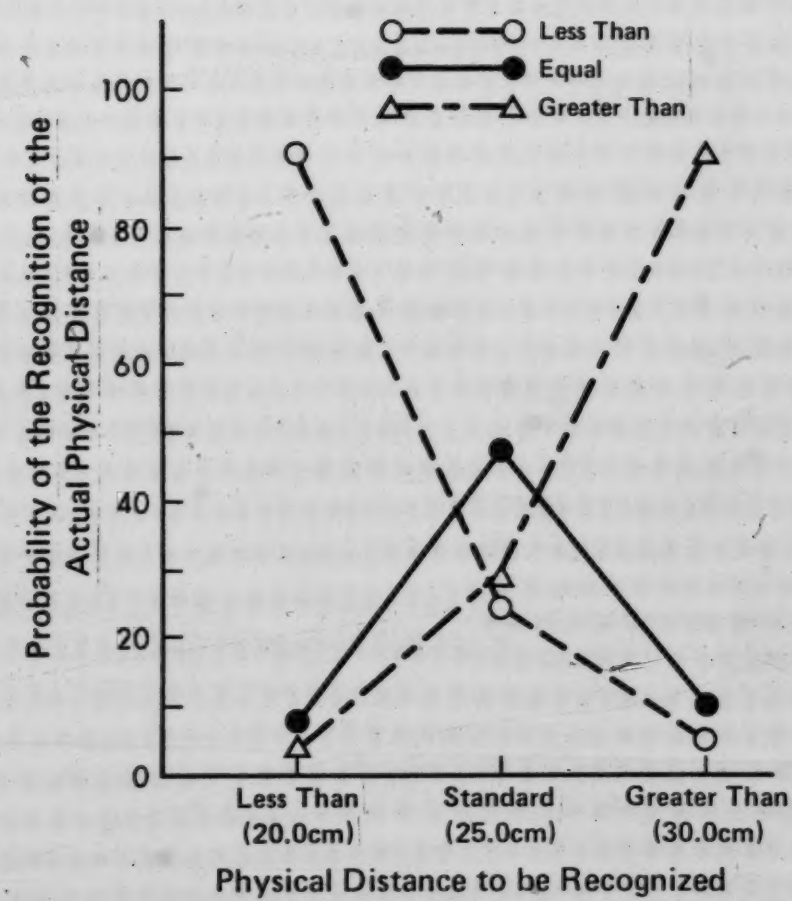


Figure 26. Recognition judgement probabilities for the physically less than (20.0 cm), equal to (25.0 cm) and greater than (30.0 cm) movement lengths for the long distance.

subjected to a 2 x 3 analysis of variance with repeated measures. The only significant finding was for criterion movement length, $F(1,46) = 8.46$, $p<.01$. The differences between perceived errors and actual distances for the short and long criterion distances were 0.7 cm and 1.6 cm, respectively. Although no other significant differences were found, subjects tended to under-estimate the actual difference between the criterion and recognition distances when making any adjustment.

Discussion

Modified movement recognition was found to decrease recognition performance and accentuate response biasing tendencies in Experiment 10. The inclusion of multiple recognition distances corresponding to the types of judgements subjects were required to make had positive effects on recognition performance in Experiment 11. Recognition performance in the present experiment was found to be between these two 'extremes'. The probability of a correct response was not as high as in Experiment 11 but the response biasing tendencies shown in Experiment 10 virtually disappeared. Consequently, modified movement recognition and multiple recognition distances seem to interact to produce an intermediate recognition performance.

The analysis of the distance data indicates that the subjects were fairly accurate at making appropriate adjustments to equalize recognized movement distances. However, these adjustments were more accurate for the short distance than the long distance. It also appears that although appropriate adjustments in distance were attempted, these adjustments under-estimated actual differences between criterion

and recognition distances, thus producing absolute recognition distances corresponding to those response tendencies reported in Experiments 9 and 10.

GENERAL DISCUSSION

Performance on a short-term motor memory task is governed by the strength of the memory for the stimulus information and by several factors not related to short-term memory processes including movement extent, movement range and subject strategy. Since these factors effect both reproduction and recognition, they should be accounted for in experimentation on the short-term retention of movement information. This is only possible if researchers are cognizant of how these factors operate. The purpose of the present series of experiments was to investigate the relationship between these factors and the reproduction and recognition of distance information.

The effect of movement extent on distance reproduction has been reported by several researchers (Pepper & Herman, 1970; Laabs, 1973; Marteniuk, 1973). Short distances are more accurately and precisely reproduced than long distances, as measured by absolute error and variable error, respectively. This result was replicated in the present studies; however, while the numerical size of the errors was greater for the long distance, the perceptual size of the errors may have been no larger. The proportional size of the errors was actually smaller for the long distance than the short distance. It could be therefore, that the encoding of distance is on some sort of relative magnitude basis (Henry, 1976) and information from short and long movements is equally available for distance reproduction (Diewart, 1975).

The research on distance recognition has also demonstrated definite but inconsistent performance differences for short and long

movements. Kantowitz (1974) found that recognition performance improved with longer distances. For same judgements short distances were better recognized than long distances in the present study, but for difference judgements performance was similar for the two movement distances. Consequently, it appears performance for both distance reproduction and recognition is sensitive to changes in movement length, and modifications in performance due to movement extent must be separated from those due to changes in the memory trace in investigations of the short-term retention of movement information.

The utilization of a movement range in a distance reproduction experiment also can alter performance, producing the central tendencies associated with the range effect (Pepper & Herman, 1970; Laabs, 1973). Such shifts in algebraic error in the direction of the mean movement distance have been discussed in terms of assimilation and adaptation-levels (Laabs, 1973), but there is increasing evidence that these tendencies are more complex than existing models indicate. The present research demonstrates that a large number of trials is usually required in a distance reproduction study for subjects to determine the experimental movement range and produce the central tendencies of the range effect. Moreover, these central tendencies develop faster for short distances than long distances. These two characteristics of the range effect and the observation that subjects show differential rates in the development of range effect tendencies makes it difficult to utilize the range effect in the prediction of individual performance. The response patterns associated with the range effect are probably best employed as general per-

formance descriptors for groups of subjects being examined over large numbers of trials.

The present research suggests that movement range can influence distance recognition as well as distance reproduction. There is a tendency to give *less than* judgements for short distances and *greater than* judgements for long distances when recognition performance is incorrect. Although these response tendencies are opposite to the central tendencies associated with the range effect, they may be related to the corresponding response sets of the range effect in the following manner. An overshooting set for short distances would favour *less than* judgements if the criterion and recognition distances were of equal length, as was the case in the present recognition experiments. To increase the probability of *equal to* or *greater than* judgements, the recognition distances would have to be lengthened in proportion to the build-up of the overshooting set. The reverse situation would occur for long distances. The development of an undershooting set with the increased probability of *greater than* judgements would require the corresponding shortening of the recognition distances for the appropriate compensation to occur. While in the present research there was no endeavor to demonstrate this possible relationship between recognition performance tendencies and the response sets of the range effect, the influence of movement range on distance recognition performance is certainly suggestive of this type of relationship.

The present discussion thus far has considered how short-term motor memory performance is a result of movement extent and movement

range, in addition to the strength of the memory. The accuracy and precision of distance reproductions and the probability of correct distance recognition judgements vary over different movement lengths. The range of movements in a distance reproduction or recognition experiment produces certain response tendencies, and these tendencies are not permanent but develop for each new movement range. The frequency with which these tendencies have been reported has prompted research on the locus of the range effect in short-term memory tasks. Previous studies (Ascoli & Schmidt, 1969; Keele & Ells, 1972; Marteniuk, 1973) have indicated that the range effect is largely independent of short-term memory since there is little change in the tendencies associated with the range effect over a retention interval. Further evidence for this conclusion was produced in the current research. The performance patterns of the range effect were not developed over trials when distances were made from memory. Range effects were demonstrated, however, when either kinesthetically or visually presented distances were reproduced. They also occur when both visual and kinesthetic information is available during the presentation of the criterion movement (Wilberg & Girouard, 1975). The range effect, therefore, seems to be independent of memory and is probably related to encoding and comparison processes.

Encoding becomes a factor in the development of range effect tendencies when stimuli contain conflicting or inaccurate information. Wilberg and Girouard (1975) made both visual and kinesthetic information available during the presentation of criterion movements. They found that the presence of conflicting visual information could disrupt the acquisition of kinesthetic information, and that the

central tendencies of the range effect could be reversed by an assimilation process with such visual information. Subjects were provided with inaccurate information in the present research. Light and tone signals were utilized to identify criterion movement end-points and these end-points created the perception of movements longer than the actual criterion movements. The range effect tendencies also failed to be demonstrated in this situation. Other variables influencing the encoding of information, such as instruction presentation (Experiment 5), can alter reproduction performance but not influence the range effect.

The comparison between the criterion and reproduction movements would appear to be the other process related to the development of the range effect. Generally on each trial of a movement reproduction experiment the reproduction movement must be compared to the criterion movement. Over trials, as the subject perceives the movement range, the performance patterns associated with the range effect are demonstrated. When no criterion distances are presented for reproduction (Experiment 3) and subjects make movements from memory, the response tendencies associated with the range effect are not produced. Therefore, the comparison stage for the criterion and reproduction movements would seem to be critical to the development of range effect tendencies.

While this comparator stage would appear to be a locus for the range effect, the nature of the transformation has yet to be determined. Perceptual biasing of the stimulus information is one possibility, or the actual comparator mechanism may be subject to modification over trials. One characteristic of this transformation that

has been demonstrated concerns visual dominance. The visual presentation of criterion distances produces an accelerated development and greater stability in the range effect tendencies than the kinesthetic presentation of criterion distances. In addition, subjects report being able to ascertain the movement range after only a few trials with visual presentation of the criterion distances and usually this is not possible when the criterion distances are kinesthetically presented.

Given that the response tendencies associated with the range effect are related to encoding and comparison processes, the next concern evolves around how movement reproductions are adjusted to produce these tendencies. The present research indicates that both criterion and reproduction movements are made in a similar manner. These movements usually have similar average velocities on a given trial and consist of an acceleration, constant velocity and deceleration phase. The constant velocity phase is the section of the reproduction movement adjusted to generate the central tendencies associated with the range effect. This phase is lengthened over trials for the reproduction of short distances and shortened over trials for the reproduction of long distances. The acceleration and deceleration phases of both criterion and reproduction movements represent a small proportion of the complete movement, and these two phases sustain only minor adjustments during movement reproduction.

The type of movement strategy employed by subjects may best account for the constant velocity phase being adjusted during distance reproductions. Kantowitz (1974) suggests that reproduction

tasks favour a strategy of moving at a constant velocity. The research by Marteniuk, Shields and Campbell (1972) and the present experiments on movement velocity support this contention. Criterion and reproduction movements on a given trial are made at about the same average velocity, and the acceleration, constant velocity and deceleration phases of criterion and reproduction movements are highly related. Therefore, given this type of movement strategy, the development of range effect tendencies should correspond with changes in the duration of the constant velocity phase of reproduction movements, and this relationship was demonstrated in the current research.

A model for distance reproduction based on the three movement phases and the above response strategy could have the following form. The acceleration and deceleration phases of the movement would be constants and contain no significant information. They would serve only to initiate and terminate the movement reproduction. The constant velocity phase would consist of the memory trace for the criterion movement and the performance patterns associated with the range effect. Therefore, the constant velocity phase would be the meaningful section of the movement, but it would be difficult to analyze due to it reflecting both memory trace strength and range effect tendencies. This analysis might be possible, however, if the effects of memory trace strength and movement range on performance were considered additive.

Response strategy, in addition to movement extent and movement range, can also modify distance reproduction performance. Bracketing response strategies, the under-estimation and over-estimation of

criterion distances, were employed in the present reproduction experiments. It was found that subjects can accurately adopt response strategies and that response strategy formation can supercede the central tendencies associated with the range effect. These findings correspond with those conducted on the reproduction of time (Buckolz, 1974). Subjects can be under-estimators or over-estimators, and tendencies in distance recall data that appear to correspond with range effect tendencies may be due to the response strategies adopted by the subject.

Response strategy as defined in the present research could not be appropriately applied in the current examination of distance recognition; however, the recognition (test) distances in several experiments were manipulated according to bracketing type response strategies. The recognition distances were either physically less than, equal to or greater than the criterion distance. The inclusion of these multiple recognition distances not only improved recognition performance, but reduced the response tendencies reported in recognition judgements where these recognition distances were not employed. There are various possible explanations for this improvement in recognition performance. Jacoby (1972) and Mandler (1972) have shown what seems to be positive effects of organization on recognition, and perhaps with multiple recognition distances subjects were better able to categorize or implement some other form of organization on which to base recognition judgements. An alternative explanation comes from the levels of processing model proposed by Craik and Lockhart (1972). In this model further processing can take place between

or within three processing domains; physical, phonemic and semantic. Further processing within a domain is termed elaboration and facilitates the distinguishing of a target item from similar items in memory (Lockhart, Craik & Jacoby, 1975). Therefore, in the framework of this model, employing multiple recognition distances in the present research could permit further analysis of the stimulus movements at the same processing level and provide for more accurate recognition judgements.

There has been no attempt in the present research to compare the possible processes underlying recall and recognition. This has been a popular concern, however, in experimental psychology. The generation-discrimination theory (Kintsch, 1970; Brown, 1976) assumes there are two basic processes involved in the retrieval of items from memory, only one of which is included in recognition. The first process entails the guided generation or retrieval of items from memory storage. Each item is then subjected to a discrimination or recognition test and this test is based on a familiarity judgement. The item judged most familiar will be recalled or selected for recognition. Lockhart, Craik and Jacoby (1976) in their levels of processing model propose that two basic modes exist for both recall and recognition - reconstruction and scanning. Reconstruction is an operation in which some approximation to the initial encoding event is generated in the perceptual/cognitive system. Scanning involves the examination of recent episodic traces for the presence of some salient feature of the retrieval probe. Since the same two retrieval modes exist for both recall and recognition, the authors argue that recall and recognition are basically the same process.

The present research, although not suggestive of distance reproduction and recognition being essentially the same process, does indicate that both distance reproduction and recognition are influenced in a similar manner by movement distance and movement range. Following the precedent set by experimentation in verbal memory, it is likely, however, that comparisons of reproduction and recognition processes for movement information will be attempted. This will prove to be difficult due to the paucity of investigations on distance recognition. In addition, researchers must be cognizant of those variables such as movement extent, movement range and response strategy that alter reproduction and recognition performance but are not related to short-term memory processes.

References

Adams, J.A. Human tracking behavior. Psychological Bulletin, 1961, 58, 55-79.

Adams, J.A. and Dijkstra, S. Short term memory for motor responses. Journal of Experimental Psychology, 1966, 71, 314-318.

Alderson, G.J.K. Perception of velocity and prediction of motion. Paper presented at The Fourth Canadian Psycho-Motor Learning and Sports Psychology Symposium, Waterloo: 1972.

Annett, J. The role of action feedback in the acquisition of a simple motor response. Journal of Motor Behavior, 1970, 2, 217-221.

Annett, J., Galby, C.W. and Kay, H. The measurement of elements in an assembly task - the information output of the human motor system. Quarterly Journal of Experimental Psychology, 1958, 10, 1-11.

Ascoli, K.M. and Schmidt, R.A. Proactive interference in short-term motor retention. Journal of Motor Behavior, 1969, 1, 29-36.

Bahrick, H.P., Fitts, P.M. and Schneider, R. Reproduction of simple movements as a function of factors influencing proprioceptive feedback. Journal of Experimental Psychology, 1955, 49, 445-454.

Beggs, W.D.A., Andrew, J.A., Baker, M.L., Dove, S.R., Fairclough, I. and Howarth, C.I. The accuracy of non-visual aiming. Quarterly Journal of Experimental Psychology, 1972, 24, 515-523.

Beggs, W.D.A. and Howarth, C.I. The movement of the hand towards a target. Quarterly Journal of Experimental Psychology, 1972, 24, 448-453.

Blick, K.I. Short-term memory for length. Journal of Experimental

Psychology, 1969, 82, 224-230.

Bower, G.H. Stimulus-sampling theory of encoding variability. In A.W. Melton and E. Martin (Eds.), Coding Processes in Human Memory, New York: V.H. Winston & Sons, 1972.

Brown, J. An analysis of recognition and recall and the problems in their comparison. In J. Brown (Ed.), Recognition and Recall, London: Wiley, 1976.

Buckolz, E. Human Time Estimation: Selected Topics. Paper presented at The Sixth Canadian Psycho-Motor Learning and Sports Psychology Symposium, Halifax: 1974.

Carey, S.T. and Lockhart, R.S. Encoding differences in recognition and recall. Memory and Cognition, 1973, 1, 297-300.

Craft, J.L. and J.V. Hinrichs. Short-term retention of simple motor responses: similarity of prior and succeeding responses. Journal of Experimental Psychology, 1972, 87, 297-302.

Craik, F.I.M. A "Levels of Analysis" view of memory. In P. Pliner, L. Krames and T.M. Alloway (Eds.), Communication and Affect: Language and Thought, New York: Academic Press, 1973.

Diewart, G.L. Retention and coding in motor short-term memory: a comparison of storage codes for distance and location information. Journal of Motor Behavior, 1975, 1, 183-190.

Duffy, T.M., Montague, W.E., Laabs, G.J. and Hillix, W.A. The effect of overt rehearsal on motor short-term memory. Journal of Motor Behavior, 1975, 7, 59-63.

Edwards, E. Research note on the study of hand motions. Perceptual and Motor Skills, 1965, 20, 1098.

Ellis, H.C. Stimulus encoding processes in human learning. In G.H. Bower (Ed.), The Psychology of Learning and Motivation, New York: Academic Press, 1973.

Fitts, P.M. The information capacity of the human motor system in controlling the amplitude of movement. Journal of Experimental Psychology, 1954, 47, 381-391.

Fry, R.D. Prior Entry. Unpublished manuscript, 1975.

Fuchs, A.H. The progression-regression hypotheses in perceptual-motor skill learning. Journal of Experimental Psychology, 1962, 63, 177-182.

Gomez-Toussaint, N.A. and Chevalier-Girard, N. Strategies and encoding of location in short-term motor memory. Paper presented at the Seventh Canadian Psycho-Motor Learning and Sports Psychology Symposium, Quebec City, 1975.

Hall, C.R. and Leavitt, J.L. Encoding and retention characteristics of direction and distance. Journal of Human Movement Studies, 1977.

Helson, H. Adaptation-level as a basis for a quantitative theory of frames of reference. The Psychological Review, 1948, 55, 297-313.

Helson, H. Adaptation Level Theory. New York: Harper & Row, 1964.

Herman, L.M. and Bailey, D.R. Effects of retroactive and proactive interference in motor short-term memory. Journal of Experimental Psychology, 1970, 89, 407-417.

Henry, F. Personal communication, 1976.

Hollingworth, H.L. The inaccuracy of movement. Archives of Psychology, 1909, 2, 1-87.

Hollingworth, H.L. The central tendency of judgement. Journal of

Philosophy, Psychology and Scientific Methods, 1910, 7, 461-469.

Howarth, C.I., Beggs, W.D.A. and Bowden, J. The relationship between speed and accuracy of movement aimed at a target. Acta Psychologica, 1971, 35, 207-218.

Jacoby, L.L. Effects of organization on recognition memory. Journal of Experimental Psychology, 1972, 92, 325-331.

Jacoby, L.L. Test appropriate strategies in retention of categorized lists. Journal of Verbal Learning and Verbal Behavior, 1973, 12, 675-682.

Jones, B. The role of central monitoring of efference in short-term memory for movements. Journal of Experimental Psychology, 1974, 102, 37-43.

Kantowitz, B.H. Modality effects in recognition short-term motor memory. Journal of Experimental Psychology, 1974, 104, 522-529.

Keele, S.W. and Ells, J.G. Memory characteristics of kinesthetic information. Journal of Motor Behavior, 1972, 4, 127-134.

Kintsch, W. Models for free recall and recognition. In D.A. Norman (Ed.), Models of Human Memory, New York: Academic Press, 1970.

Klein, R.M. and Posner, M.I. Attention to visual and kinesthetic components of skills. Brain Research, 1974, 71, 701-711.

Laabs, G.J. Retention characteristics of different reproduction cues in motor short-term memory. Journal of Experimental Psychology, 1973, 100, 168-177.

Leuba, J.H. A new instrument for Weber's law; with indications of a law of sense memory. American Journal of Psychology, 1892, 5, 370-384.

Lockhart, R.S., Craik, F.I.M. and Jacoby, L.L. Depth of processing in recognition and recall: Some aspects of general memory system. In J. Brown (Ed.), Recognition and Recall, London: Wiley, 1976.

Mandler, G. Organization and recognition. In E. Tulving & W. Donaldson (Eds.), Organization and Memory, New York: Academic Press, 1972.

Marshall, P.H. Recognition and recall in short-term motor memory. Journal of Experimental Psychology, 1972, 95, 147-153.

Marteniuk, R.G. Retention characteristics of motor short-term cues. Journal of Motor Behavior, 1973, 5, 249-259.

Marteniuk, R.G. A cognitive information processing model of motor short-term memory. In B.S. Rushal (Ed.), The Status of Psycho-Motor Learning and Sport Psychology Research, Halifax: Sport Science Associates, 1975.

Marteniuk, R.G. and Roy, E.A. The codability of kinesthetic location and distance information. Acta Psychologica, 1972, 36, 471-479.

Marteniuk, R.G., Shields, K.W. and Campbell, S. Amplitude, position, timing and velocity as cues in the reproduction of movement. Perceptual and Motor Skills, 1972, 35, 51-58.

Melton, A.W. The concept of coding in learning-memory theory. Memory and Cognition, 1973, 1, 508-512.

Melton, A.E. and Martin, E. Coding Processes in Human Memory. New York: V.H. Winston & Sons, 1972.

Nacson, J., Jaeger, M. and Gentile, A. Encoding processes in short-term motor memory. Paper presented at the Fourth Canadian Psycho-

Motor Learning and Sport Psychology Symposium, Waterloo, 1972.

Parducci, A. Category judgement: a range frequency model. Psychological Review, 1965, 72, 407-418.

Pepper, R.L. and Herman, L.M. Decay and interference effects in the short-term retention of a discrete motor act. Journal of Experimental Psychology, 1970, 83, (2, Pt. 2).

Posner, M.I. Characteristics of visual and kinesthetic memory codes. Journal of Experimental Psychology, 1967, 75, 103-107.

Posner, M.I. and Konick, A.F. On the role of interference in short-term retention. Journal of Experimental Psychology, 1966, 72, 221-231.

Poulton, E.C. Range effects are characteristic of a person serving in a within-subjects experimental design - a rely to Rothstein. Psychological Bulletin, 1974, 81, 201-202.

Roy, E.A. Encoding kinesthetic extent information; the importance of strategy. Paper presented at the Canadian Psychological Association, Quebec City, 1975.

Schutz, R.W. and Roy, E.A. Absolute error: the devil in disguise. Journal of Motor Behavior, 1973, 5, 141-153.

Stelmach, G.E. Prior positioning responses as a factor in short-term retention of a simple motor task. Journal of Experimental Psychology, 1969, 81, 523-526.

Stelmach, G.E. Short-term motor memory: have we made any progress? In M.G. Wade & R. Martens (Eds.), Psychology of Motor Behavior and Sport. Human Kinetics Publishers, 1974.

Stelmach, G.E. and Barber, J.L. Interpolated activity in short-term

motor memory. Perceptual and Motor Skills, 1970, 30, 231-234.

Stelmach, G.E. and Scott Kelso, J.A. Memory trace strength and response biasing in short-term motor memory. Memory and Cognition, 1975, 3, 58-62.

Stelmach, G.E., Scott Kelso, J.A. and Wallace, S.A. Preselection in short-term motor memory. Journal of Experimental Psychology: Human Learning and Memory, 1976.

Stelmach, G.E. and Walsh, M.F. Response biasing as a function of duration and extent of positioning acts. Journal of Experimental Psychology, 1972, 92, 354-359.

Sternberg, S., Knoll, R. and Gates, B. Prior entry re-examined: effect of attentional bias on order perception. Paper presented to the Psychonomic Society, St. Louis, Missouri, 1971.

Taylor, F.V. A study of the acceleration pattern of manual corrective responses. American Psychologist, 1947, 2, 340.

Taylor F.V. and Birmingham, H.P. Studies of tracking behavior, 11. The acceleration pattern of quick manual corrective responses. Journal of Experimental Psychology, 1948, 38, 783-795.

Tomlinson, R.W. Control impedance and precision of feedback as parameters in sensori-motor learning. Ergonomics, 1972, 15, 33-47.

Trumbo, D., Milone, R. and Noble, M. Interpolated activity and response mechanisms in motor short-term memory. Journal of Experimental Psychology, 1972, 93, 205-212.

Vince, M.A. Corrective movements in a pursuit task. Quarterly Journal of Experimental Psychology, 1948, 1, 85-106.

Wilberg, R.B. and Girouard, Y. On the locus of the range effect in a short-term motor memory paradigm. In Mouvement, Revue de 1' asociation des professionnels de 1'activite physique du Quebec, 1975.

Wilberg, R.B. and Girouard, Y. Information sur les distances, effect de 1'entendue des stimuli et memoire motrice a court-terme. Canadian Journal of Psychology, 1976, 30, 63-71.

Wilberg, R.B. and Hall, C.R. Movement extent, response bias, and bracketing behavior. In J. Broekhoff (Ed.), Physical Education, Sports and the Sciences, Eugene Oregon: Microfilm Publication, 1976.

Wilberg, R.B. and Tannis, G. Effects of end-point control in motor short-term memory. Paper presented at The Sixth Canadian Psycho-Motor Learning and Sports Psychology Symposium, Halifax: 1974.

Woodworth, R.S. The Accuracy of Voluntary Movement, New York: New Era Printing Company, 1899.

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Hall, C.R. and Wilberg, R.B. Distance reproduction, velocity and the range effect. Journal of Human Movement Studies (in press).

Hall, C.R. and Leavitt, J.L. Encoding and retention characteristics of direction and distance. Journal of Human Movement Studies (in press).

Wilberg, R.B. and Hall. C.R. Movement extent, response bias and bracketing behavior. In J. Braekhoff (Ed.), Physical Education, Sports and the Sciences. Eugene: Microfilm Publications, 1976.